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ABSTRACT

Identification Of Optimal Locations For Small-Scale Erosion Control Structures On Fort Hood, Texas

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A number of small-scale rock-fill erosion control structures (check dams) have been installed in gullies in a small watershed on Fort Hood. Watershed erosion parameters were measured to evaluate the effectiveness of the structures. The rates of gully scour and sediment accumulation between check dams were calculated from cross-sectional and longitudinal profile measurements and sediment capture and analysis over time. Integration of these measurements with data on precipitation, antecedent moisture, storm event water accumulation, soils, bedrock geology and slope resulted in quantification of the effectiveness of the check dams in reducing gully-erosion soil loss within the watershed. Spatial analysis of these data over a larger region using the ArcView GIS package resulted in a map layer identifying candidate sites for additional check dams to reduce soil erosion. Final map layers were distributed to the GIS users in the Fort Hood Public Works and Installation Training Area Management offices.

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Identification Of Optimal Locations For Small-Scale Erosion Control Structures On Fort Hood, Texas

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in Partial Fulfillment of the

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of

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By

Christopher E. Kramer

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CONTENTS

FIGURES

Appendices

TABLES

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For assistance in preparation of the SWAT model input data, model runs, and other essential data, I wish to thank Dr. Jeff Arnold, Dr. Raghavan Srinivasan, Susan Nietsch and June Jones III of the Temple, Texas Agricultural Research Service.

DEDICATION

This work is dedicated to my wife Lisa and daughter Lindsey, whose patience and understanding have been essential throughout the preparation of this study.

It is also dedicated to the continuing battle against erosion and the loss of irreplaceable land.

CHAPTER ONE

Introduction

Fort Hood is a United States Army installation located in central Texas, 100 miles south-southeast of Dallas and 60 miles north of Austin (Fig. 1). The terrain on Fort Hood (Fig. 2) is generally rolling, with interspersed ridges and plateaus (McCaleb, 1985).

There are nearly 41,000 military personnel and more than 12,000 tracked and wheeled military vehicles on the installation (Fort Hood Command Information Summary, 1998). The post covers 214,351 acres, much of which (138,940 acres) is used for field training of personnel in the use of vehicles and equipment under simulated wartime conditions. The large number of soldiers conducting training leads to high rates of traffic on a daily basis all year long. This traffic consists of a wide variety of vehicles and equipment, including the well-known "Humvee", larger cargo and transport trucks, and many different heavy tracked vehicles. In addition to these military vehicles, military and civilian digging equipment and civilian off-road equipment work in many locations. There is also a considerable amount of foot traffic associated with training.

This varied combination of vehicle and personnel traffic is a significant source of ground disturbance, and results in the removal of large amounts of vegetative cover and widespread exposure of the soil (Knott, 1980). The high rates of traffic and intermittent but occasionally heavy storm events (Wilson, 1973) mean that control of soil erosion is a constant effort (Downing, 1980). Fort Hood land managers and users must, despite shrinking budgets, accomplish erosion control at low cost, within regulatory guidelines, and with minimal interference with daily training.

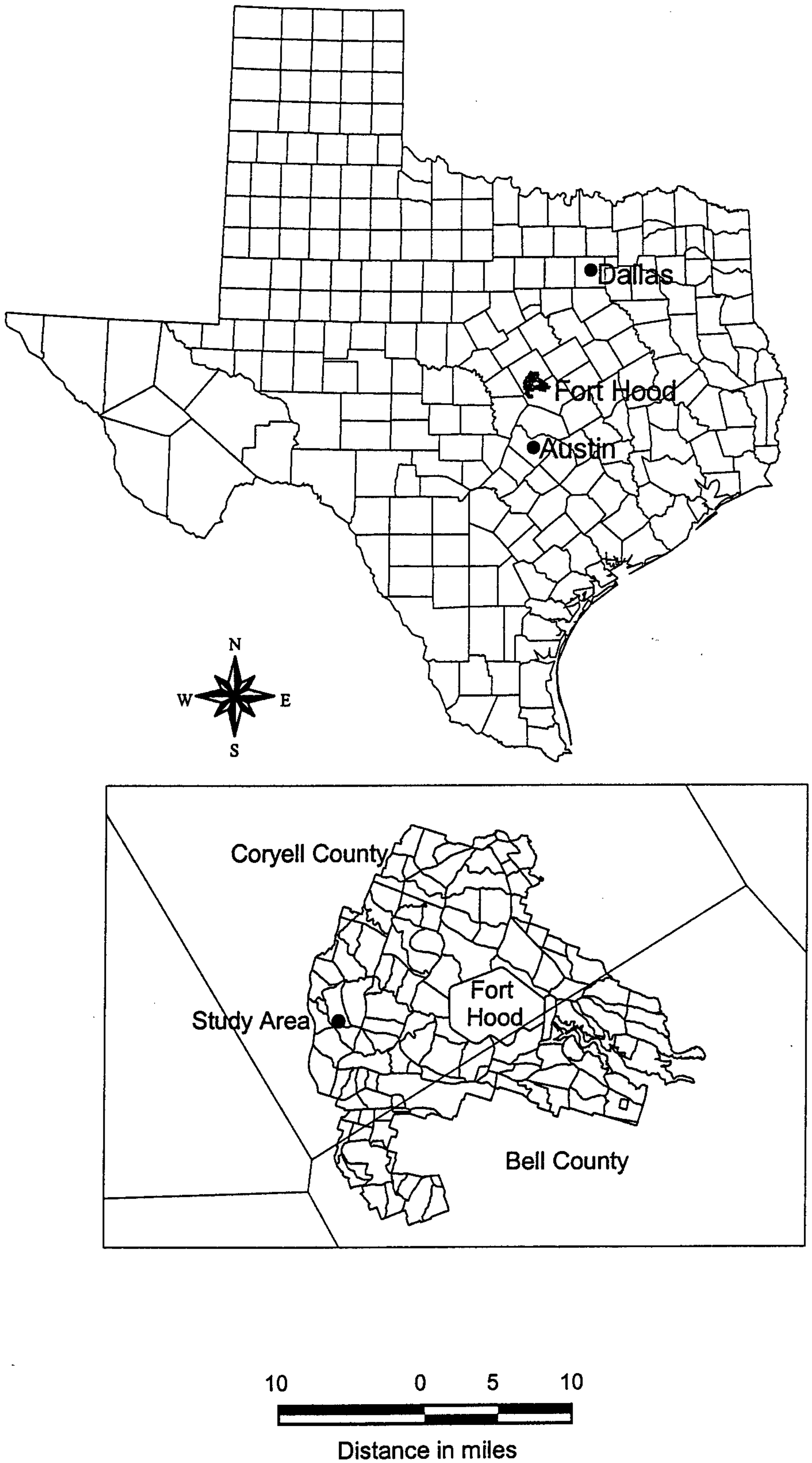


Figure 1. General study area location in Central Texas.

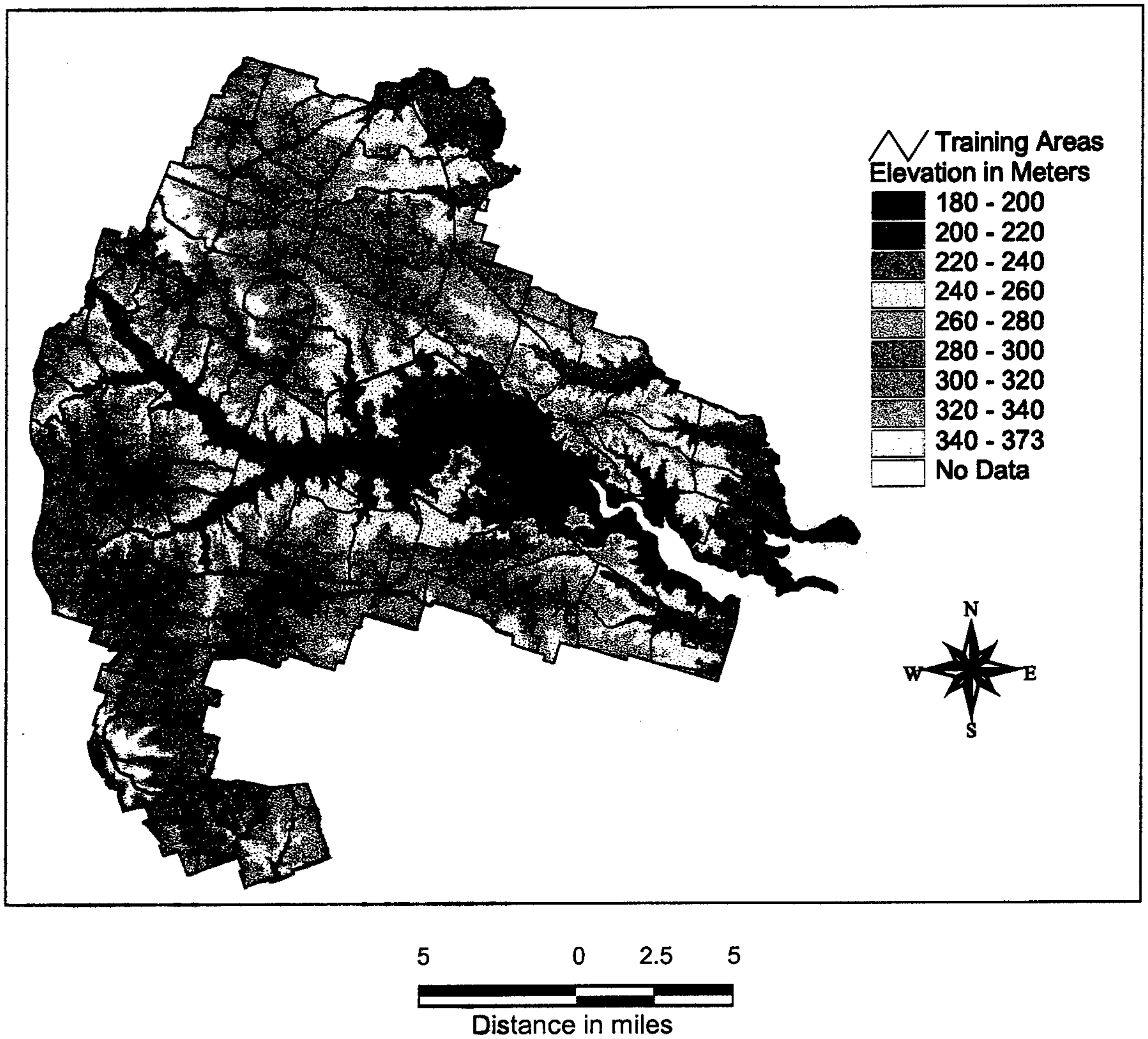


Figure 2. Relief map of Fort Hood.

In 1993, the Soil Conservation Service and Fort Hood performed a joint assessment of the scope of the problem of soil erosion at several locations on Fort Hood and the methods proposed to control it. Bircket (1993) performed detailed analyses of soil erosion on several areas on the installation. His analyses included numerous iterations of the Universal Soil Loss Equation (USLE) to determine projected soil loss with and without sediment control structures, and also included estimates of average annual gully erosion.

While sheet and rill erosion from land and weathered tank roads account for an average of 93 percent of total erosion on Fort Hood (Bircket, 1993), gully erosion is a problem due to the significant amounts of soil lost and to the hazard gullies pose to vehicle traffic. Uncontrolled gullies grow continuously, cause loss of valuable training area, and add unwanted sediment load to stream systems. Even small gullies can be hazardous to vehicles, especially during night movement. Fort Hood land managers have recently refocused on gully erosion as a problem requiring near-term treatment.

There were three primary objectives of this study. The first was to quantify the rate of total erosion (total erosion = sheet and rill erosion + gully erosion) in the study area. The second was to use the erosion rates to assess the effectiveness of, and effective lifespans of, a specific Best Management Practice (BMP), namely rock check dams (RCDs), which Fort Hood has recently emplaced to control gully erosion. The third objective was to quantify the environmental conditions that initiated gully erosion and use the data in a GIS (Geographic Information Systems) analysis to identify the scope of potential gully erosion problems on Fort Hood. This process is significant in that it allows land managers to allocate the few available resources to field reconnaissance of the identified locations to determine the degree of need for site control, and reduce or eliminate serious erosion problems more rapidly than previously possible.

The study site was chosen for several reasons. All site sediment output enters a nearby sediment catchment structure, allowing assessment of both erosion and deposition. A similar erosion assessment was performed in 1993 on the study area, and provides a basis for comparison. Small erosion control structures were emplaced in some of the gullies in the site, allowing small-scale monitoring of erosion processes. The site

is not in an off-limits or restricted area, and was generally accessible for data gathering. Finally, the site was specifically named as a concern by land managers.

This study uses the common desktop GIS ArcView (Environmental Systems Research Institute, 1996), and a detailed soil erosion (sheet and rill erosion) model called SWAT (Soil and Water Assessment Tool) (Arnold, 1998; Srinivasan, 1998) which incorporates groundwater and infiltration processes plus many other environmental parameters. Field measurements of gully erosion and measurement of sediment accumulation in the large sediment catchment structure are added to provide a more complete assessment of the processes occurring in the study area. Also, this study was conducted on a military installation, a type of land use which involves unique environmental and off-road vehicle maneuver conditions.

Study Area

The study area covers a single watershed in western Fort Hood. This area was divided into three smaller areas (Fig. 3) based on observed erosion processes in each area. Area One covers thirty-five acres and contains the monitoring site, which includes two monitored gullies and part of a hill named Antelope Mound. Area Two is south of Area One, contains unmonitored gullies, and covers twenty-eight acres. Area Three is west of Areas One and Two, contains one small unmonitored gully, and covers forty-seven acres. There is a sediment catchment in the western part of the study area which collects all sediment lost from the watershed.

The study area is bounded on the north and west by low ridgelines, on the south by Elijah Road, and on the east by Antelope Mound. The relief of the mound (Fig. 4) provides an excellent view of the surrounding terrain, leading to frequent use as a vehicle

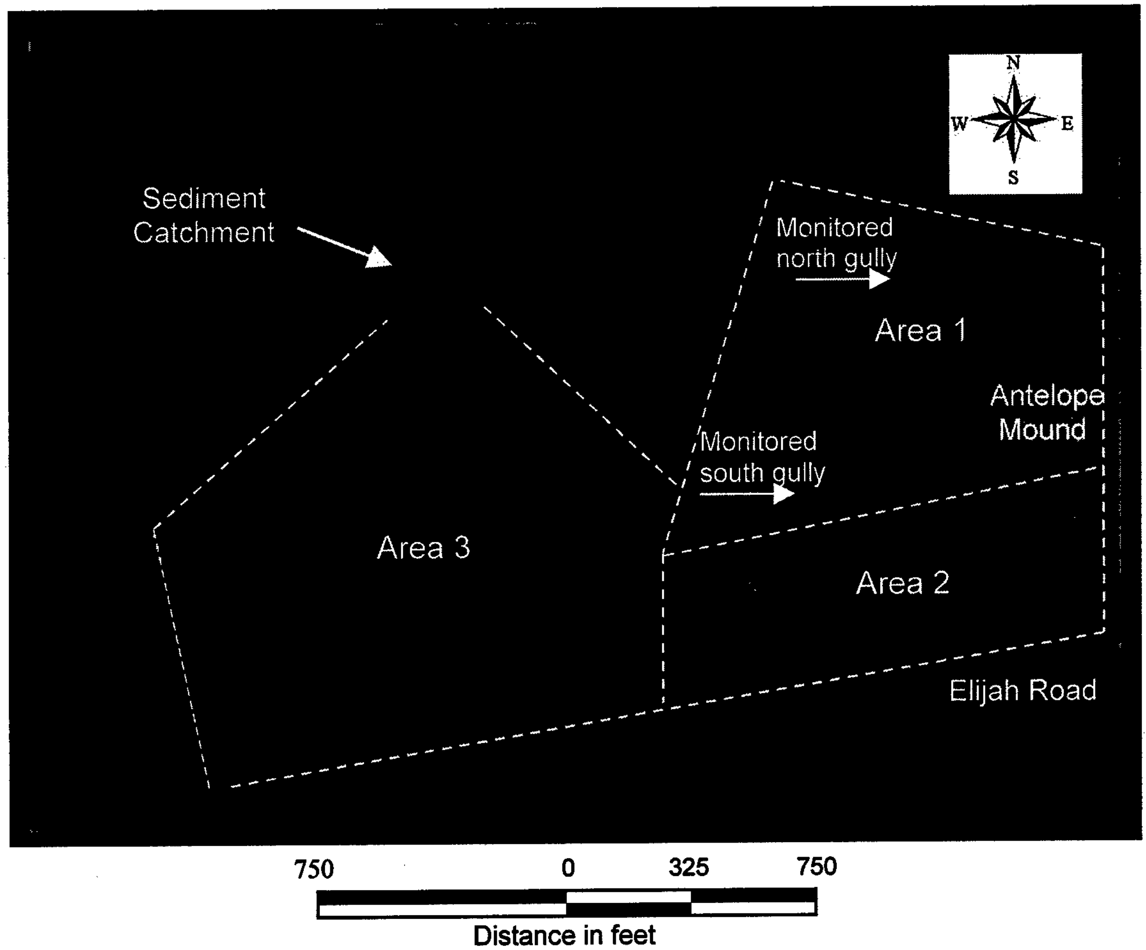


Figure 3. Digital image of Areas One, Two and Three of the study area, west of Antelope Mound, Fort Hood, Texas.

and personnel assembly area and heavy vehicle and foot traffic. The loss of protective vegetative cover from the top of the mound due to heavy traffic (Fig. 5) has resulted in greatly increased erosion (Simpkins and Gustavson, 1987). A network of gullies forms on the footslope of Antelope Mound, and extends to the west for 800 feet. The monitoring site is immediately west of Antelope Mound in Area One, and was itself divided into four zones (Fig. 6) based on slope, soils and land cover.

The two gullies indicated in Figure 6 were monitored during this study. Figures 7 and 8 are views looking downchannel (west) from the heads of the south and north

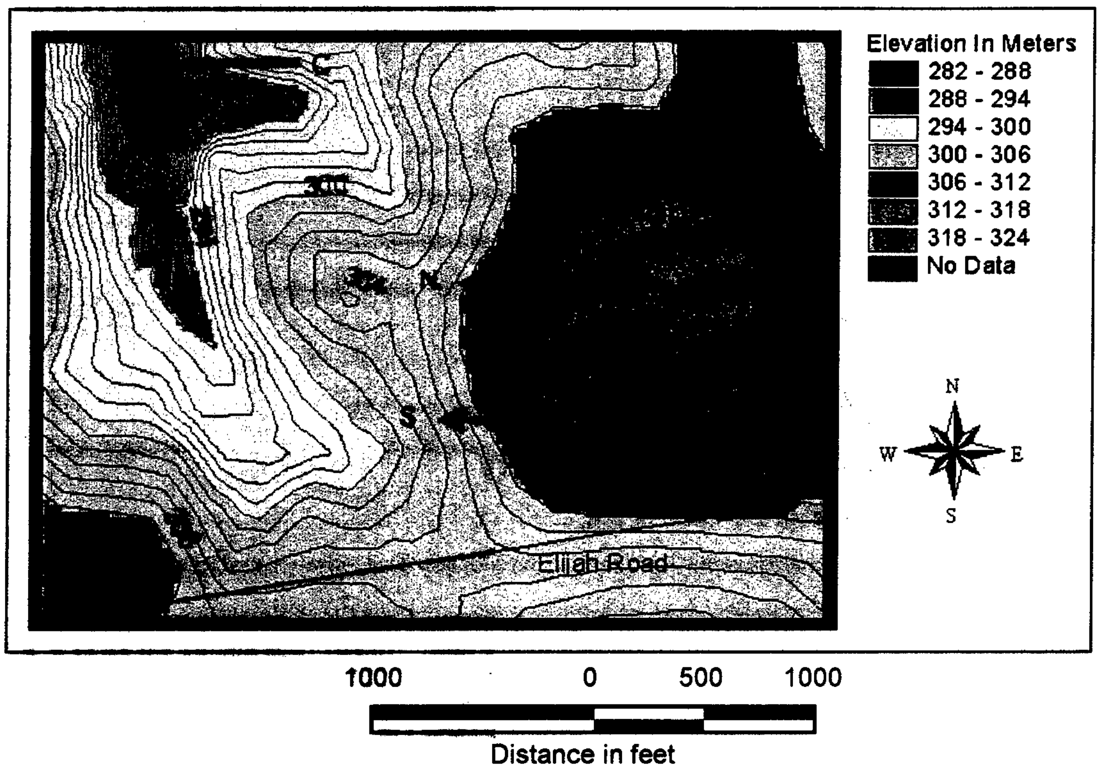


Figure 4. ArcView 3.1 view of the topography of Antelope Mound and study area. The heads of the monitored north and south gullies are marked with (N) and (S), respectively; the sediment catchment is indicated with a (C).

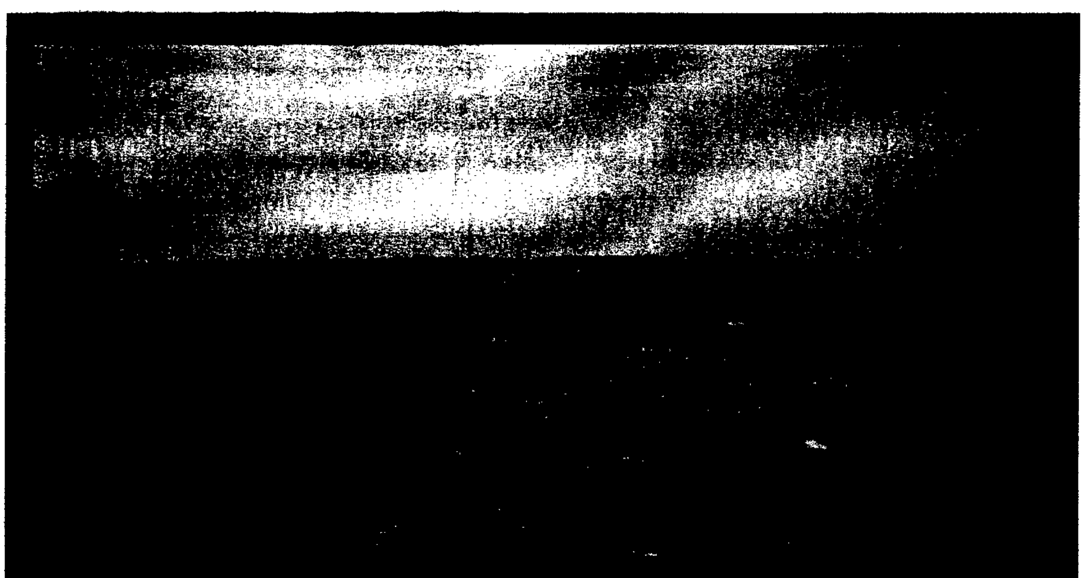


Figure 5. Top of Antelope Mound after normal summer traffic, photo from July 1999.

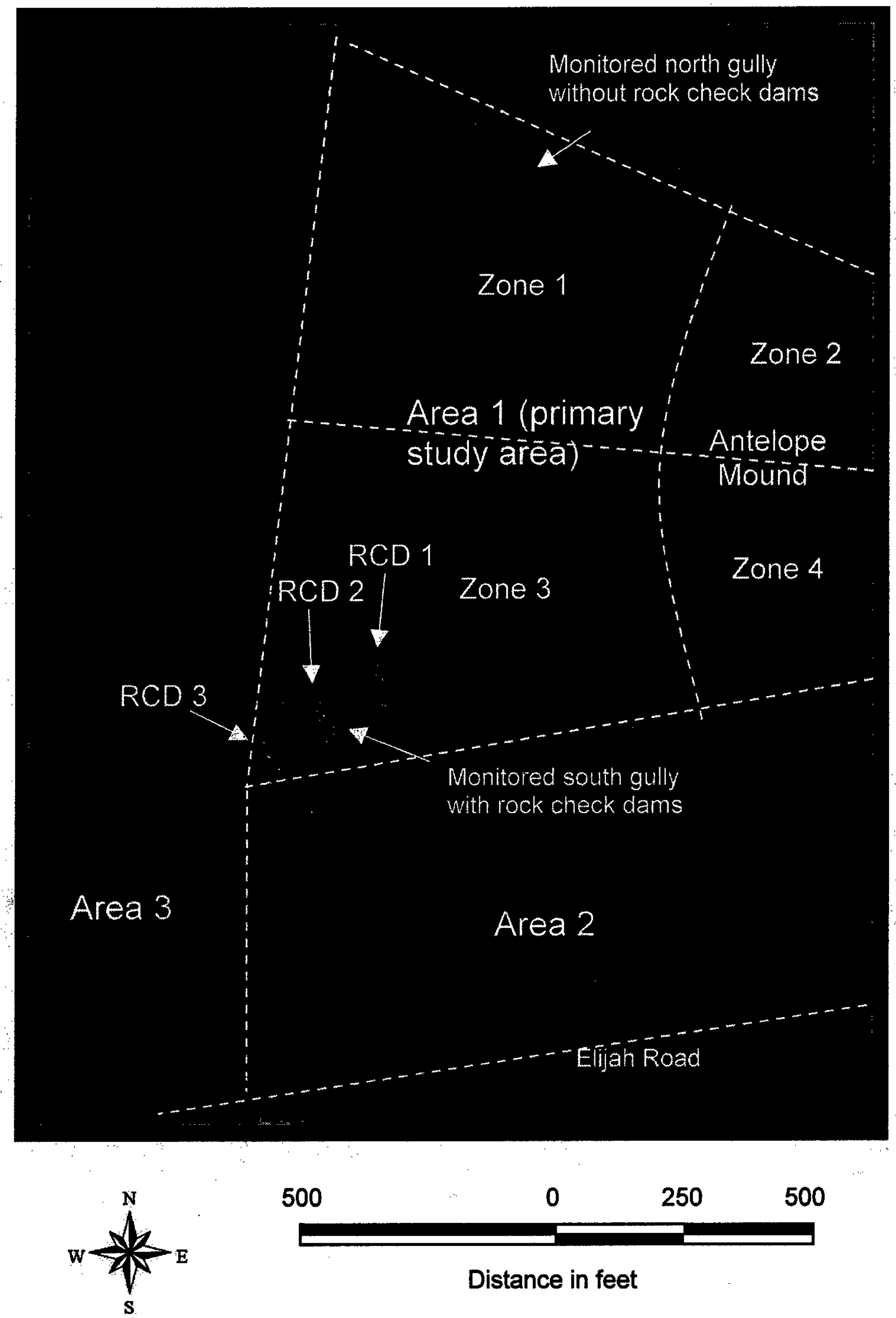


Figure 6. Digital image of the study area, showing area boundaries, monitored north and south gullies, locations of rock check dams (RCDs), and subdivision of Area One into zones.

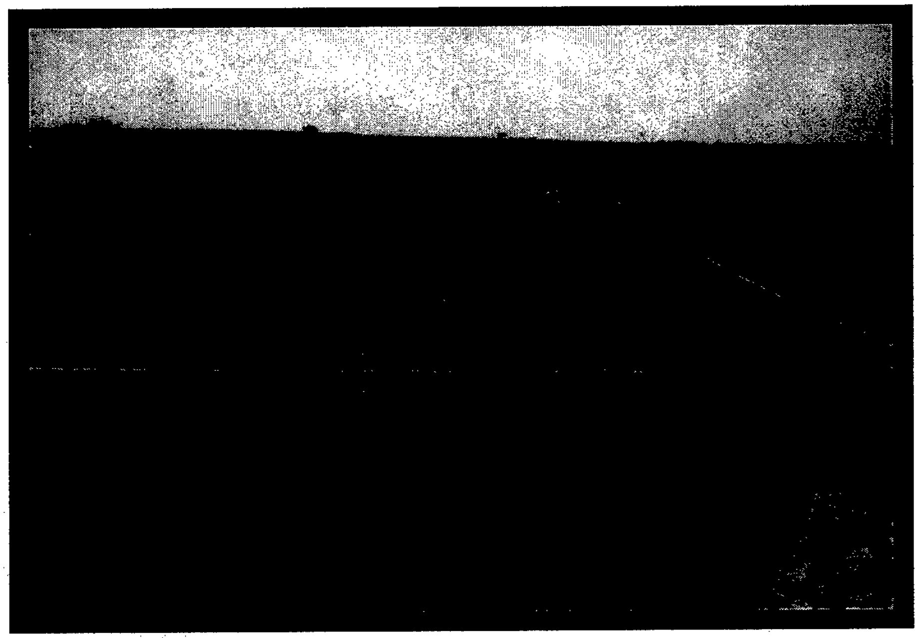


Figure 7. View from the head of the south gully looking downgully (west). Gully is nine feet wide and thirty inches deep at this location.

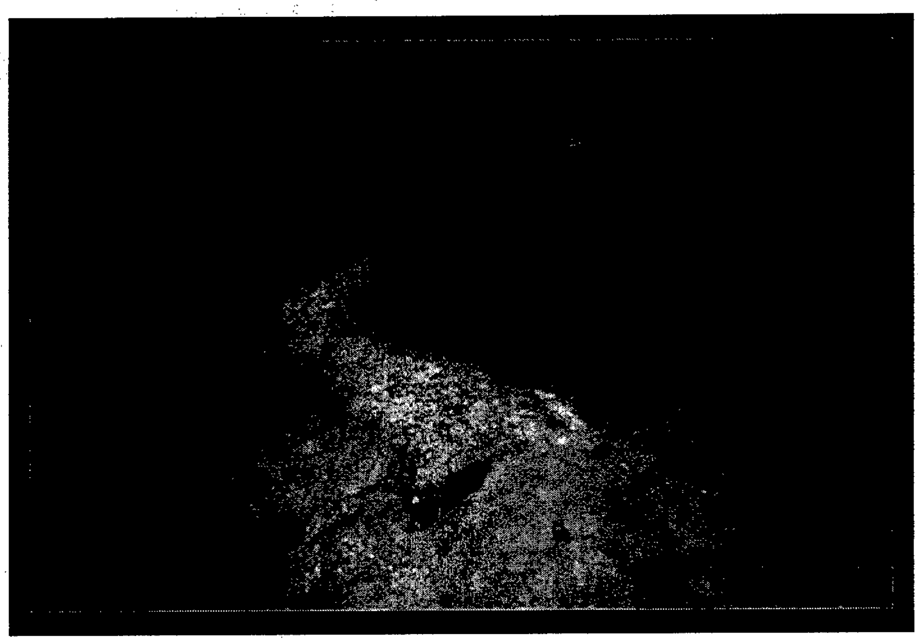


Figure 8. View from the head of the north gully looking downgully (west). Gully is twelve feet wide and three feet deep at this location.

gullies, respectively. Rock check dams were emplaced in the south gully in March 1999 to provide a means of slowing storm runoff water flow, capture eroded sediment, and slow or stop the gully erosion. The gullies were monitored to determine their geometry change over time and the amount and character of sediment eroding into the gullies. Instruments were placed in the gullies to monitor water levels and sediment concentrations.

The north gully cuts into the calcareous Upper and Lower Walnut Clay (Barnes, 1979), part of the Cretaceous-age Fredericksburg Group of the Comanchean Series (Fassauer, 1979). The Walnut Clay in the study area (Flatt, 1976) consists of clay-rich, nodular limestone, which is often exposed in the bottom of the monitored north gully. The Walnut Clay also consists of thin alternating beds of calcareous clay and limestone, which is present only at the last monitoring site in the north gully. There is no exposure of Walnut Clay in the south gully. The Walnut Clay underlies all soils in the study area.

Study area soils (Fig. 9) formed from the Upper and Lower Walnut Clay (McCaleb, 1985). The Brackett-Topsey association (BtC2) and Slidell Clay (SiB) formed from the Upper Walnut Clay, and the Nuff very stony silty clay loam (NuC) formed from the Lower Walnut Clay. The north gully channel begins in the Slidell Clay and ends in the Nuff soil. The south gully channel begins and ends in the Slidell Clay.

The climate is temperate and subhumid (McCaleb, 1985). The average annual temperature fluctuation is approximately 18 degrees per day. Coryell County temperatures historically range from an average maximum of 96 degrees Fahrenheit in July to an average minimum of 33 degrees in January (Ramos, 1997). Historic average rainfall amounts in inches per month in Killeen, Texas (the city that bounds Fort Hood to

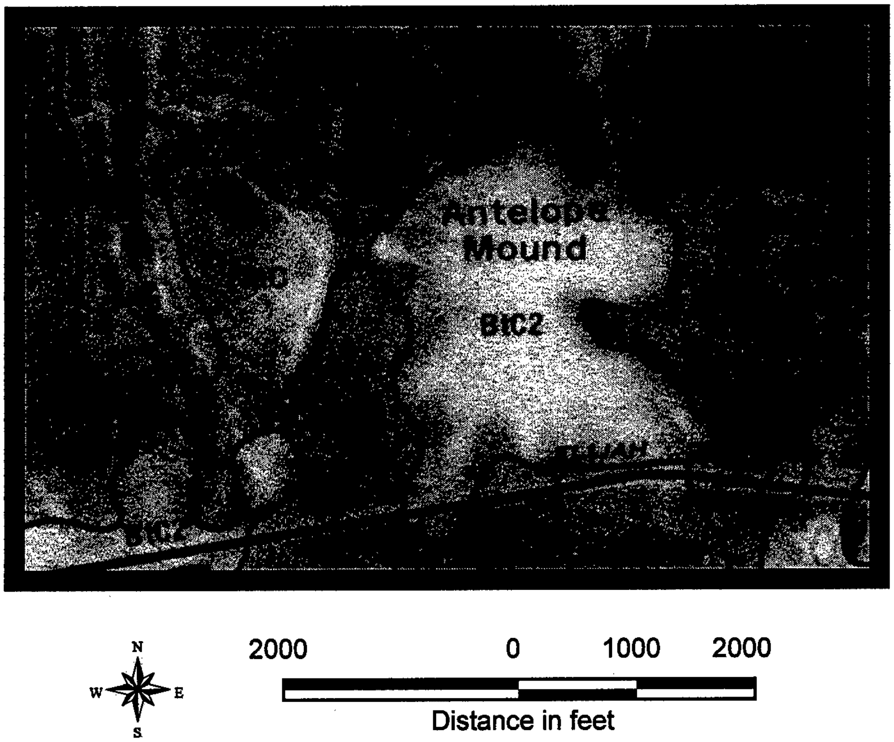


Figure 9. Study area soils. Diagram from Coryell County soil survey (McCaleb, 1985)

the south) are shown in Table 1. The data were derived from the National Climate Data Center (Lott, 1999), and reflect averages from the 28 complete years of data since 1945.

Vegetation is seasonal and dependent on the extent of vehicular ground disturbance, livestock grazing and precipitation. The dominant grasses at the study site are King Ranch Bluestem and Texas Wintergrass, and the dominant forbs are Broomweed, Western Ragweed, Prairie Tea, and Frogfruit. All flora were identified by Laura Sanchez of the Nature Conservancy on Fort Hood.

Grasses comprise 80 to 90 percent of the area flora, forbs comprise 5 to 10 percent, and woody plants make up 5 percent (McCaleb, 1985). There are no trees near or upslope from either monitored gully. Vehicle traffic has removed the vegetation from the top of Antelope Mound and disturbed the soil over most of the area of the mound.

Table 1. Historic precipitation in inches per month at Killeen, Texas.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1.9	2.5	2.5	3.0	4.6	3.5	1.6	2.5	3.5	3.8	2.4	2.3	34.2

The land cover is open rangeland, and is populated by the vegetation described above. There is one paved road to the south, one major north-south dirt road to the west, and numerous interspersed vehicle trails, some of which cross the gully systems. An estimated 30 percent of the vegetative cover has been removed from Area One due to the effects of vehicle traffic. There are no streams or ponds upslope from either gully.

The runoff and sediment trap catchment located downslope (west) of the gully outlets (Fig. 3) was built in 1992 to capture the sediment being lost from the study area.

The land is used primarily for the movement of wheeled and tracked military equipment. This off-road vehicle use increases erosion, particularly because it develops rill and gully-like patterns which channel rainwater and contribute to deep penetration of erosion (Knott, 1980). In the early 1960's, the population and number of vehicles on Fort Hood increased by more than 30 percent, with an accompanying increase in vehicle-induced erosion. Free-roaming range cattle are often found in the area, and there is no managed agriculture in the study area.

CHAPTER TWO

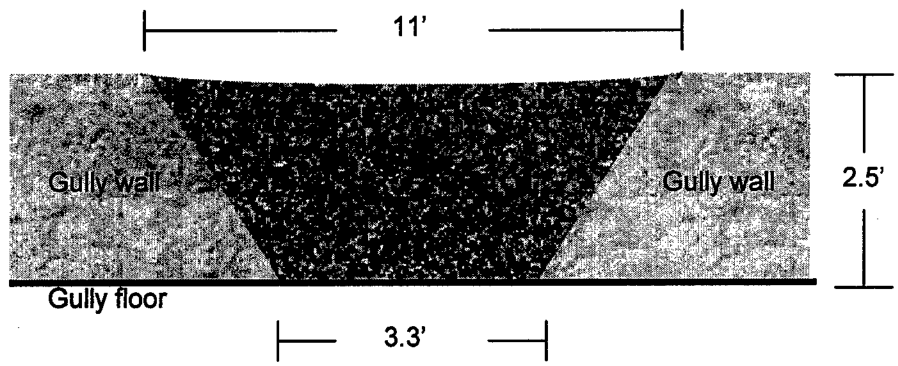
Methods

Gullied areas on Fort Hood which had been previously outfitted with rock check dams were inspected to locate a site in which two moderately large gullies were situated relatively close together, were in essentially the same physical environment, and with one of the gullies not outfitted with check dams to provide a source of data for comparison. The gullies at Antelope Mound best met these criteria. The general appearance and in-gully configuration of the dams are shown in Figure 10, and a photo of RCD 2 in the monitored south gully is shown in Figure 11.

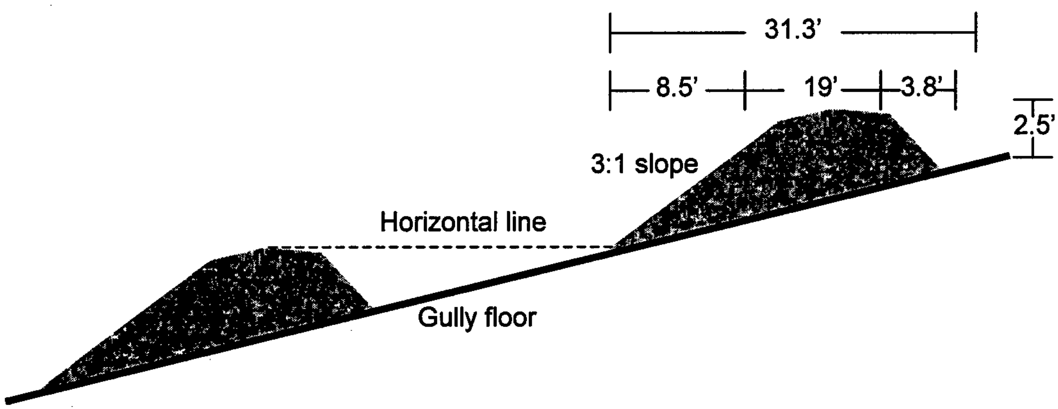
Field Monitoring

Field monitoring equipment was designed to record temporal changes in gully channel geometry. Monitoring was also done to indicate scour and/or sediment deposition, plus sediment concentrations and grain size distributions in post-flood event stormwater in the gullies. Water surface height and total precipitation after rainfall were also recorded. The area surrounding the gullies was surveyed to determine slope. A static cone penetrometer (McCarthy, 1998) was used to test the shear strength of the soil near the north gully. Field data was recorded weekly or after rainfall events from April 1999 to October 1999. Descriptions of the monitoring equipment are presented in Appendix B, and all collected field data are presented in Appendix C.

Channel geometry was monitored to determine cross-sectional area change in the two gully systems. Change was monitored at four, eight, twelve and sixteen feet upslope



View looking downchannel at face of rock dam. All listed measurements are averages in feet for dams 2 and 3 in the south gully. Rock dams have a soil core which prevents direct passage of stormwater through the structure and allows for long detention times.



Side view of gully channel and general arrangement of rock dams in channel. Measurements reflect averages in feet for the dimensions of rock dams 2 and 3 in the south gully. Dams have a blunt, nearly vertical front face and a 3:1 backside slope to prevent scour from overtopping streamflow. Top of downslope dam is intended to align horizontally with back slope of upslope dam. Dams are wide enough to easily accommodate tracked vehicle traffic.

Figure 10. General dimensions and arrangement of check dams 2 and 3 in the south gully.

from rock check dams Two (RCD 2) and Three (RCD 3) in the south gully (Fig. 12) and at four locations (Sites M - P) in the north gully (Fig. 13). The method used was similar to that used by Carlson and Olyphant (1996), but differed in that a line level and strong twine were used in this study in place of an aluminum frame, and fewer measurements were taken along the cross section.

Geometry change indicated the rate of scour or deposition and allowed an estimate of check dam lifespan and the amount of soil lost to gully erosion. The four cross-section points on the north gully were spaced out along the gully and placed where there were variances in the thickness and character of the soil and the width of the gully. Amounts of deposition and scour were determined by the methods described by Carlson and Olyphant (1996).

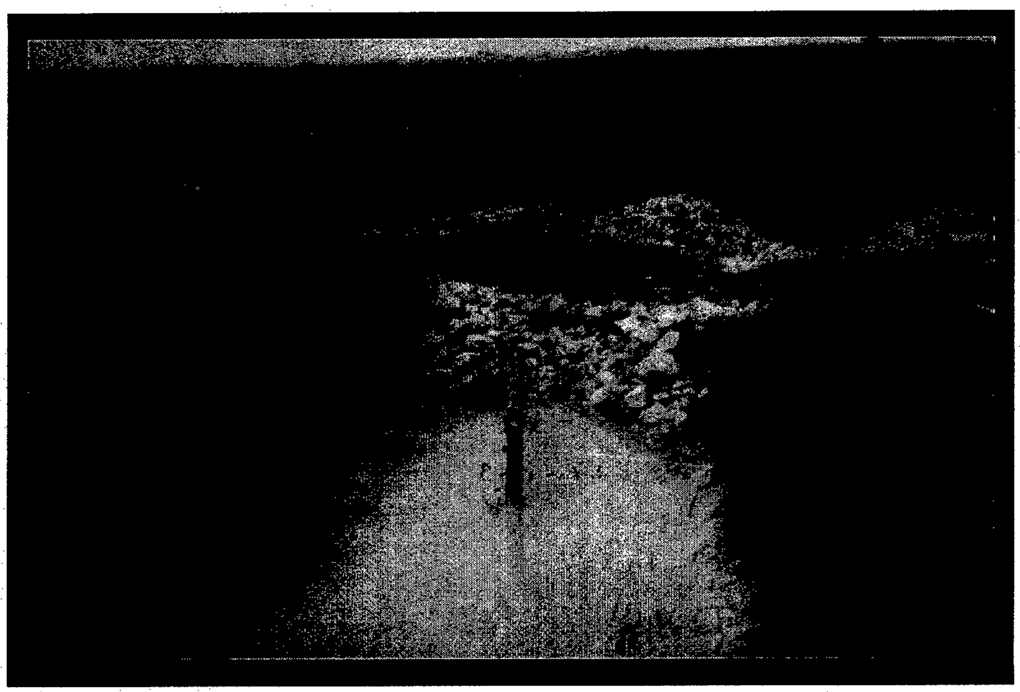


Figure 11. Photo of RCD 2 in south gully, 13 May 1999. View is looking downgully at the check dam, following a 1.9-inch rainfall on May 10. Water is approximately 20 inches deep at thalweg.

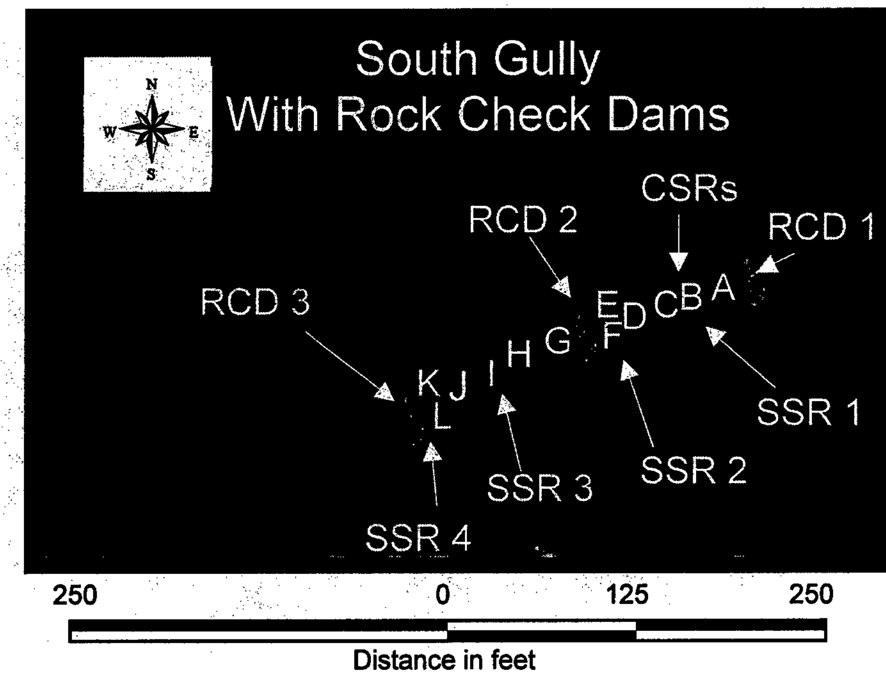


Figure 12. Locations of rock check dams (RCDs) 1 – 3, stage sediment recorders (SSRs) 1 - 4, crest stage recorders (CSRs) A - L and cross-section sites (A – L) in the south gully.

Rebar rods were emplaced at the heads of both gullies to monitor headward erosion. A two-foot rod was used at the south gully, and a five-foot rod was used at the head of the north gully due to a three-foot vertical drop at the head.

After rainfall events, stormwater pooled upslope from the check dams in the south gully, and the water level rose temporarily in the north gully. Concentrations and grain size distributions of stormwater sediment were found by sampling gully stormwater using stage sediment recorders (SSRs), as described in Appendix C. Recorders were installed at four locations (SSRs 1 –4) in the south gully (Fig. 12), and at two locations (SSRs 5 and 6) in the north gully (Fig. 13). Post-event water depth varied with antecedent moisture and the amount and intensity of precipitation, so bottles were placed at heights above the gully floor where they were most likely to collect stormwater (Appendix B).

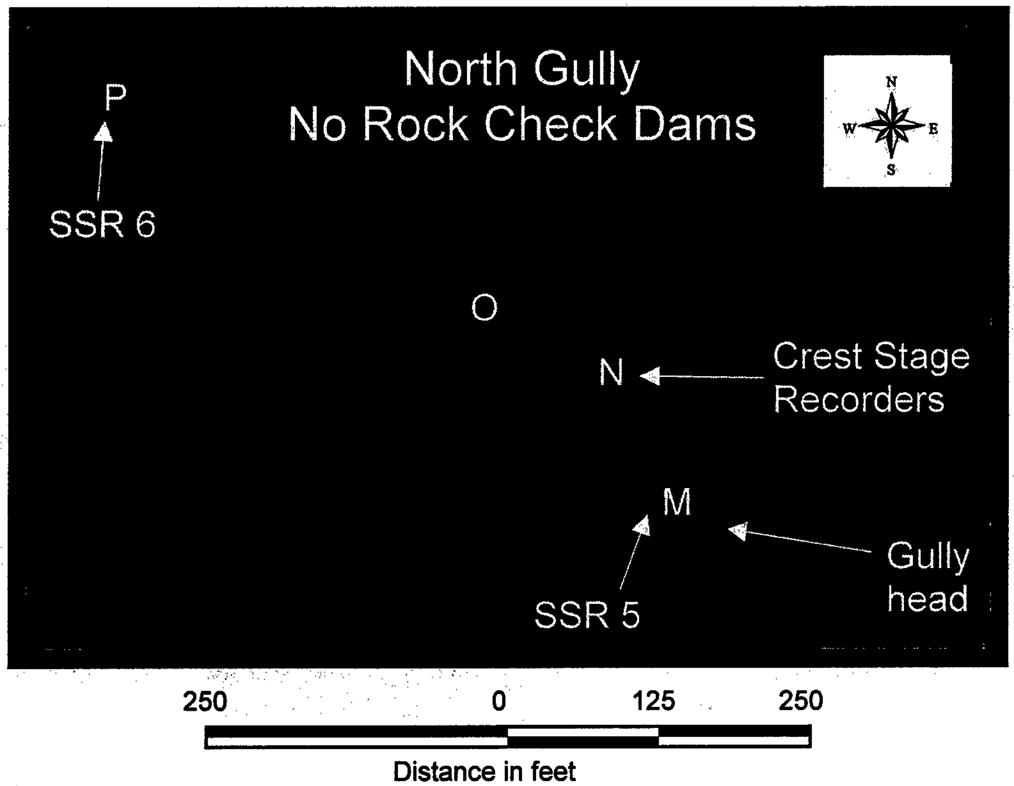


Figure 13. Locations of stage sediment recorders (SSRs) 5 and 6, crest stage recorders (CSRs) M - P and cross-section sites (M - P) in the north gully.

The maximum depth of water in the gullies after rainfall events was monitored with crest stage recorders (CSRs), as shown in Appendix B. Recorders were located at sites A – L in the south gully (Fig. 12) and at sites M - P in the north gully (Fig. 13).

Rainfall was gauged onsite with single-event gauges attached to the top of five-foot pickets near each check dam.

Area One was surveyed using a stationary laser survey instrument and moveable target. Transects were surveyed from the peak of Antelope Mound to the heads of both gullies and down each gully, noting the positions of each instrument and check dam. The sediment catchment (Fig. 3) west of Areas One and Two was surveyed to determine its volume. Water depth in the structure varies with climate, and as a result of this

fluctuation the structure was divided into submerged, aerated and intermediate zones (Fig. 14).

The amount of sediment in the catchment was estimated by measuring the depth of the sediment at thirty-seven locations throughout the catchment (Fig. 14). A "spud-bar", or hand-held probe rod, was used to measure sediment thickness in the submerged zone, which was accessed with a small boat. Hand-held boring tools were used to penetrate and measure sediment thickness in the intermediate zone. A shallow gully incision through the aerated zone showed the thickness of the sediment in the aerated zone to average twelve inches throughout. Sediment measurement locations in all zones were surveyed and plotted. The trapezoidal method was used to separately calculate the total volume of sediment in each area. All of the sediment in the structure has collected since its construction in 1992. Sediment volume in each area was converted to tons using pounds per cubic foot as a conversion factor (Bircket, 1993) for submerged clay-silt sediment (47 pcf), aerated clay-silt sediment (67 pcf), and intermediately aerated clay-silt sediment (57 pcf).

For static cone penetrometer testing, a point was randomly chosen 50 feet south of the head of the north gully, and penetrometer readings were taken at the start point and at one-foot increments along a 50-foot line moving east from the start point.

Lab Testing

Lab work consisted of suspended sediment concentration and grain size distribution determination. The suspended sediment concentration analysis was performed using the procedure described by Porterfield (1970). The sediment grain size distribution analysis was performed using the ASTM D 422-90 test.

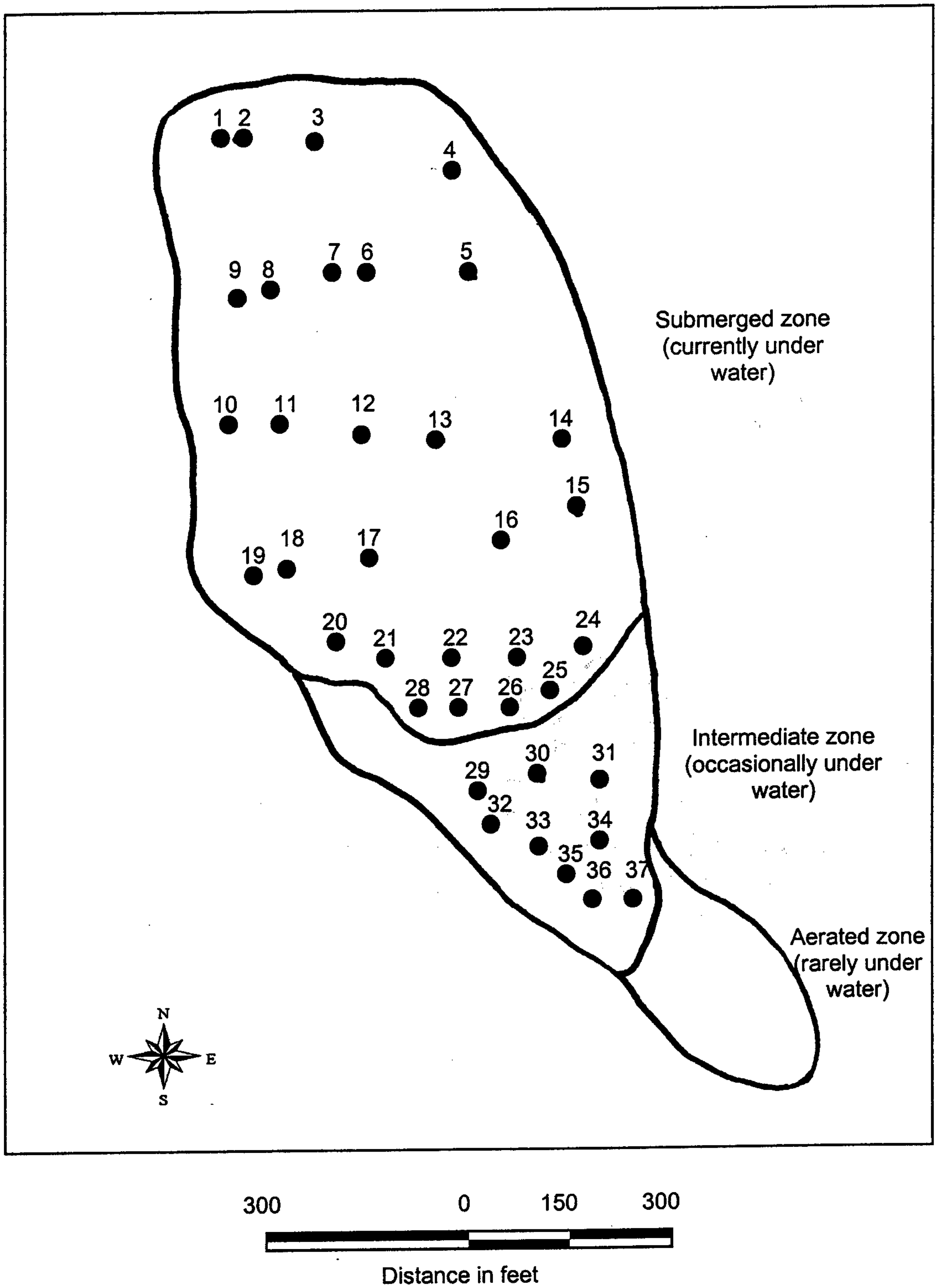


Figure 14. Subdivision of sediment catchment into zones for estimation of volume of deposited sediment.

GIS Analysis

Previous work on modeling erosion and geomorphic parameters with GIS technology was performed in Europe (DeRoo and others, 1989) in the late 1980's. The study combined the deterministic distributed parameter computer model ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulation) with a GIS to model and display the differences in surface runoff and erosion from agricultural land resulting from different simulated land uses and soil erosion control methods. The study conclusions described the lack of incorporation of sediment loss from gully erosion, the omission of the effects of groundwater flow, and the lack of modeling of surface water infiltration as weaknesses of the ANSWERS system. The end product was a graphically displayed comparison of different options of land use and erosion control.

Later, Vandaele and others (1996) evaluated the minimum environmental conditions necessary for the inception of ephemeral gullies in different locales in Europe and the U.S. The study used GIS spatial analysis capabilities, topographic map surveys, and field measurements to determine drainage area (A) and the slope of the area upland of the gullies (called the critical slope, or S_{cr}). The data was used to derive the equation $S_{cr} = .025\ A^{-.40}$ to describe the relationship. The measured slope was termed critical since a gully was known to have formed on the slope, and therefore indicative of a necessary minimum slope to begin a gully. The authors used a DEM (Digital Elevation Model) to evaluate study area elevations and slope. A DEM is a grid which is superimposed on an area with an elevation value assigned to each grid cell, providing a digital representation of the elevation of the area. The IDRISI GIS was used to compare the actual slope of each grid cell in a DEM of a site in Belgium with the critical slope,

highlighting areas where the actual slope exceeded the critical slope and is considered likely to show gully erosion. The authors deemed the results acceptable after the GIS map output was compared to actual gully locations in the study area.

The GIS analysis in this study area was performed using two procedures. The first was utilization of the Soil and Water Assessment Tool (SWAT) hydrologic model (Arnold, 1998; Srinivasan, 1998) to project the annual amount of sheet and rill erosion from the monitored watershed. The SWAT model was integrated with the ArcView GIS by the USDA's Agricultural Research Service in Temple, Texas, and the resulting interface (Neitsch, 1999) allows import of digital environmental data and gives rapid determination of the functions and processes of the surface environment. The model was run for a five-year period. Input data for the SWAT run are described in Appendix D.

The second part of the GIS analysis involved quantification of the site characteristics that contributed to the study site gully erosion problem (Miller, 1992), and use of the ArcView GIS to identify similar locations elsewhere on Fort Hood. Data for the analysis came from several sources. A ten-meter resolution DEM (each grid cell covers a 10 meter by 10 meter area and is assigned one elevation value) and an ArcView land use map coverage were provided by the Fort Hood Installation Training Area Management (ITAM) GIS section and used to derive topography and land use. Digitized county soil survey maps (Soil Survey Geographic Database, or SSURGO maps) of Coryell and Bell Counties were used for graphic display of soil extent, and recent soil characteristics data were provided by the Natural Resources Conservation Service in Temple, Texas. Characteristics of the study site which most contributed to gully erosion and were selected as criteria for the ArcView analysis were noted and quantified based on

field observations and literature review. The four equally weighted criteria used were slope, land use, soil hydrologic group, and the percentage of clay in the soil.

Slope was selected because increased slope increases overland and rill/interrill flow velocity and increases the erosive power of the moving water (Simpkins and Gustavson, 1987; Bryan, 1979; Morgan, ed., 1986). The slope of Antelope Mound in the early 1980s was as much as eight percent (McCaleb, 1985), and is now 5.8 percent. A minimum query slope factor of five percent was chosen to provide a margin of error. Slopes above 12 percent on Fort Hood are due to outcrops of hard Glen Rose, Duck Creek and Edwards Limestones (Barnes, 1979), which are much more resistant to erosion than the underlying Walnut Clay. These high-slope areas are seldom traveled, and the very small levels of traffic do not disturb the soil sufficiently to warrant inclusion in this study. Therefore the slope range used in the study was five to twelve percent.

The parts of the study area and Fort Hood most vulnerable to weathering and erosion are the areas where the majority of the traffic and exposure of soil occur (Knott, 1980). This exposure greatly increases local weathering, with an accompanying increase in erosion when rainfall and overland flow can transport the weathered material (Carson, 1971). Loss of vegetation increases surface runoff (Nawrocki and others, 1976), due to decreased infiltration (Richards and Middleton, 1978) and leads to increased erosion. Therefore, a map coverage depicting current vegetation would be the optimal choice for identifying exposed or at-risk areas. A vegetation map coverage was available but did not reflect the current effects of devegetation by vehicle traffic. A land use map coverage provided the best resolution, since the type of land use indicated the amount of vehicle

traffic and devegetation likely occurring in each area. Therefore the extent of devegetation of an area was estimated using the land use map coverage as a proxy.

There were four possible choices for land use, consisting of "maneuver area", "live fire area", "impact area" or "urban area". The "maneuver area" and "live fire" areas were selected as land use input options because these areas experience the highest rates of vehicle traffic and devegetation. The impact and urban areas are not subject to significant off-road heavy vehicle traffic and were not included.

Soil hydrologic group (Simpkins and Gustavson, 1987) indicates the amount of potential runoff. Hydrologic soil groups C and D (McCaleb, 1985) were chosen as they are most likely to experience high runoff and erosion (Richards and Middleton, 1978).

The percentage of clay in the soils was also selected due to its importance in soil erodibility. Soils that contain plastic, somewhat weathered clays, such as occur in this climate, are susceptible to extreme erosion if on disturbed areas (Bennett, 1939) or along areas with relatively well-defined and unchanging drainage patterns (Thompson, 1964). Many of the soils on Fort Hood contain slightly weathered clays, but the Slidell Clay, covering the area of both monitored gullies, is 60 percent clay. A lower limit of 50 percent clay in the query allowed for a margin of error in the final map output product.

The areas on Fort Hood most likely to experience gullying based on these criteria are hills with the defined land use and soil characteristics. Most hills do not possess the defined soil characteristics, but the low- to no-slope areas adjacent to the base of the hills often do. Most vehicle traffic is on these areas and not on the hill itself. These areas are affected by the increased overland flow caused by the high-slope hill. To identify these areas, a "buffer" zone was created which extended 500 feet away from the base of areas

on Fort Hood with five to twelve percent slope. Areas in this buffer zone with the defined land use and soil characteristics will exhibit the most gullying in practice. The ArcView map query tool was used to overlay the buffer zone, land use and soil characteristics coverages to create the final map coverage.

Climate and antecedent moisture (Bryan, 1979) were not used as criteria, despite their importance in predicting erosion, since they are relatively constant everywhere on the installation.

Soil Loss Calculations

Annual soil loss due to sheet/rill erosion and gully erosion was calculated separately for Areas One, Two and Three (Fig. 3) and compared to amounts of sediment estimated to be in the sediment catchment and the amounts of loss predicted by Bircket in the 1993 Fort Hood erosion study. Annual sheet/rill erosion soil loss in Area One (containing the monitored area) was estimated using the Universal Soil Loss Equation (USLE) (Wanielista, 1997), which is commonly used to predict sheet and rill erosion in many environmental conditions. The annual loss from Area One was calculated separately for vegetated and unvegetated conditions, indicating the effects of vehicle traffic on soil loss. The equation and its factors are shown below.

USLE equation: $A = (R)\ (K)\ (LS)\ (C)\ (P)$

A Annual soil loss from sheet and rill erosion in tons per acre
R Rainfall and runoff erosivity index for area
K Soil erodibility factor
LS Slope length and steepness factor
C Cropland or vegetation management factor
P Soil conservation method factor

Area One was divided into four zones (Fig. 6). Zones One and Two represent areas providing runoff and eroded sediment to the monitored north gully, and Zones Three and Four represent areas providing runoff and sediment to the monitored south gully. Subdivision into zones was necessary due to the variance in soil, slope and land cover between the high-slope, devegetated Antelope Mound (Zones Two and Four), and the low-slope, vegetated area below containing the gullies (Zones One and Three). USLE outputs were calculated separately for each zone and multiplied by the total acreage of the zone. A sediment delivery ratio of 0.48 was applied to the final output (Bircket, 1993) to quantify the amount of sediment actually leaving the zones.

Input factors for the USLE were derived from published data tables and previous work done in the area. The R factor was derived from previous USLE work on Fort Hood (Bircket, 1993). The Coryell County soil survey (McCaleb, 1985) provided soil erodibility K factors. Onsite surveying provided current values to determine the LS factor from a published table (Ward and Elliott, 1995). The C factor was estimated using the method described by Dissmeyer and Foster (1980) in which the conditions of plant rooting, canopy, topsoil, contour and slope are considered together to derive the factor used in the equation. The factors ranged from 0.10 in the least erosion-susceptible areas to 0.85 in the most devegetated and therefore most erosion-susceptible areas. The P factors were derived from comparisons to Birckett's work, in which a factor of 1.0 was used throughout, due to the lack of soil conservation practices.

Annual soil loss in Area One due to gully erosion was estimated using the changes in channel geometry from Sites M – P in the north gully. The amount of sediment loss from one linear foot of gully at each cross section was applied to the entire

gully by segmenting the gully and assigning rates of soil loss per segment based on the rates of loss at each cross section (Carlson and Olyphant, 1996). A delivery ratio of .70 was used to refine the gully-erosion loss estimate (Bircket, 1993), again to determine the amount of sediment leaving the monitored area. The final amount was used as a gully-equivalent standard for application to the other areas in the study. The monitored north gully (Zones One and Two of Area One) does not contribute sediment to the catchment, but the monitored south gully and two others in the southern area near the south gully do contribute to it. All contributing gullies were assigned an output value proportional to their size with respect to the monitored north gully. The volumetric output from all gullies was converted to tons using a conversion factor of 1.45 grams per cubic centimeter (McCaleb, 1985), or 90.5 pounds per cubic foot.

The USLE input factors and erosion calculations for Areas Two and Three were derived in the same manner as for Area One, and annual gully erosion in Areas Two and Three was estimated using the same process as for Area One.

CHAPTER THREE

Results

Field Monitoring and Lab Testing

Gully channel geometry change occurred at each of the six cross-section sites in the south (Fig. 15) and north (Fig. 16) gullies. Positive numbers indicate net volumetric deposition per linear foot of cross section, and negative numbers represent net volumetric scour. Measurements from the four cross-section lines at each check dam in the south gully were averaged to derive one value representing mean geometry change as a result of the check dam. Deposition was dominant at each dam. A total of 1.27 cubic yards of sediment were deposited at RCD 2, and 1.92 cubic yards were deposited at RCD 3.

In the north gully, deposition was dominant at site P and scour was dominant at sites M, N and O. Sites M, N, and O showed both scour and deposition, but scour was the net result. The north gully produced 14.7 cubic yards of sediment.

The south gully head did not move during the study period, while the north gully head moved upslope 7.8 inches.

Suspended sediment concentrations from each SSR sample bottle are shown in Figures 17 and 18. Grain size distribution curves from the eight samples tested are shown in Figure 19, with Wentworth particle sizes (Waters, 1996) shown in the figure. Particle size D_{50} values were fine silt in all top sample bottles and medium silt in all bottom bottles. The mean D_{50} for all samples was 0.018 mm, or medium silt. Post-event water levels did not reach up to the top bottles at SSRs 3, 5 and 6, or the middle bottle at SSR 5.

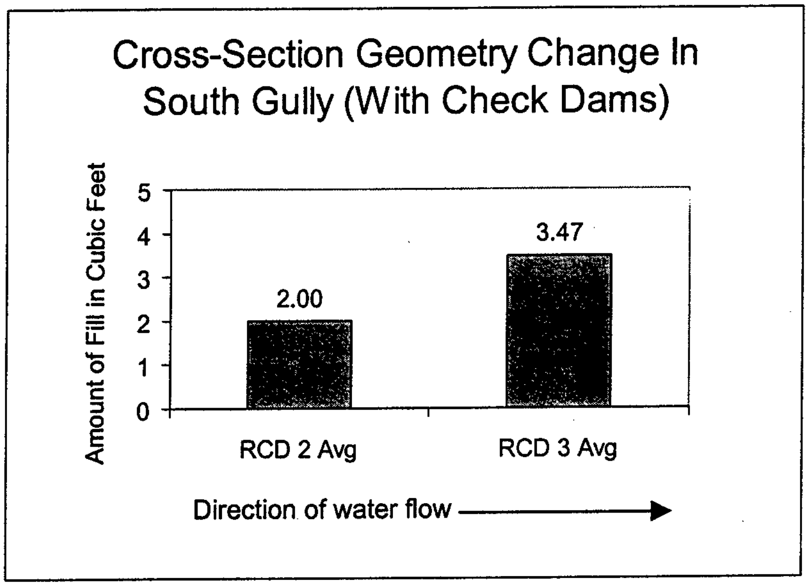


Figure 15. Cross-section change at RCDs 2 and 3 in the south gully. Deposition is dominant at both sites. Amount of fill is in cubic feet per linear foot of gully length.

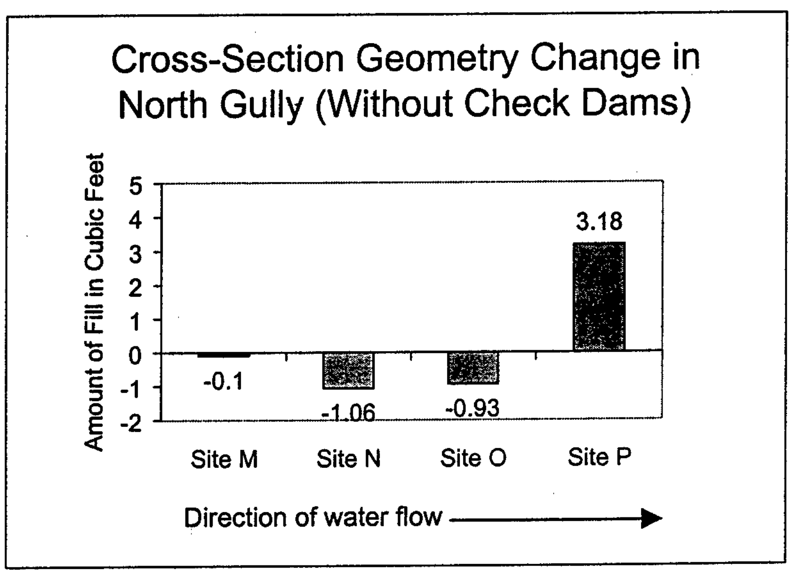


Figure 16. Cross-section change at sites M – P in the north gully. Scour is dominant at sites M – O and deposition is dominant at site P. Amounts of scour and fill are shown in cubic feet per linear foot of gully length.

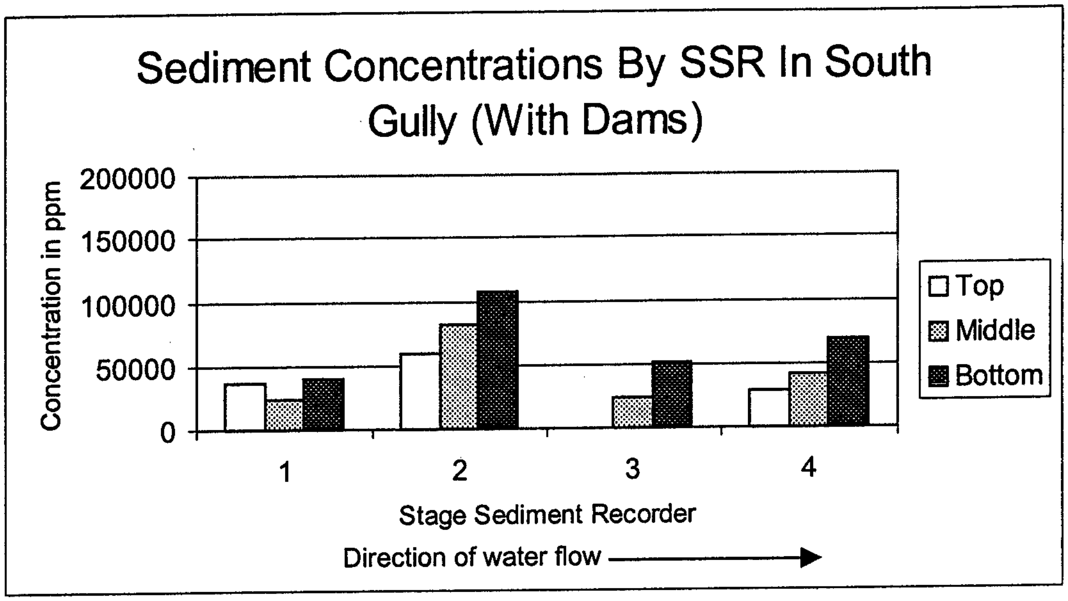


Figure 17. Suspended sediment concentrations from SSRs 1 – 4 in the south gully.

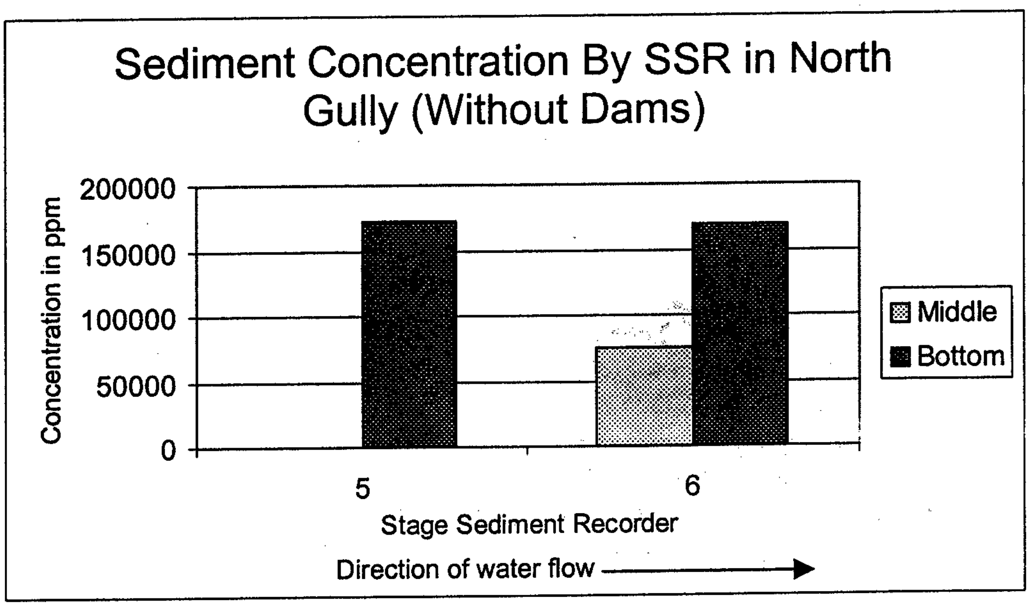


Figure 18. Suspended sediment concentrations from SSRs 5 and 6 in the north gully.

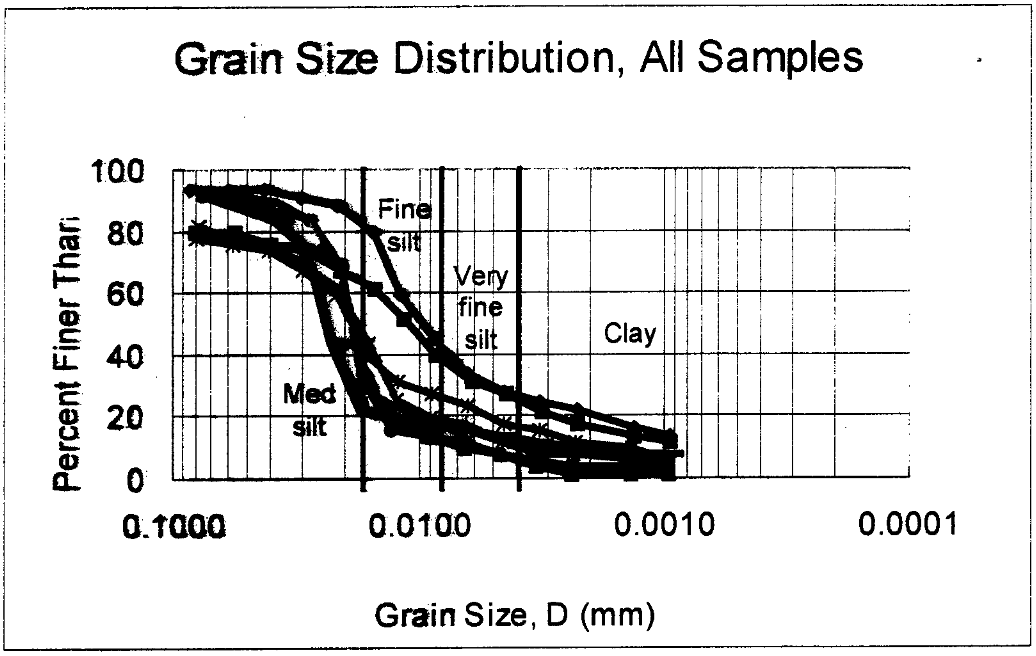


Figure 19. Suspended sediment grain size distribution.

Problems with animal and human interference with the crest stage recorders used to monitor water surface height resulted in incomplete data. The usable data from the south gully are shown in Figure 20 and from the north gully in Figure 21. The dramatic effect of antecedent moisture on water surface height is shown in Figure 21. On May 26, 0.75 inches of rain fell and caused a very shallow flow, with a water height of 0.36 inches at site O. Two days later, 1.04 inches of rain resulted in a water height of 8.5 inches at site O due to the sealing effects of the previous rainfall on the very low permeability, clay-rich soil.

Onsite rain gauge data were not used due to human and animal interference with the gauges. Rainfall data provided by Fort Hood's Robert Gray Army Airfield (RGAAF) (shown in Fig. 1) were used in figures and comparisons. These data are compared to the average monthly values for Killeen, Texas (from Table 1) in Figure 22. Rainfall during

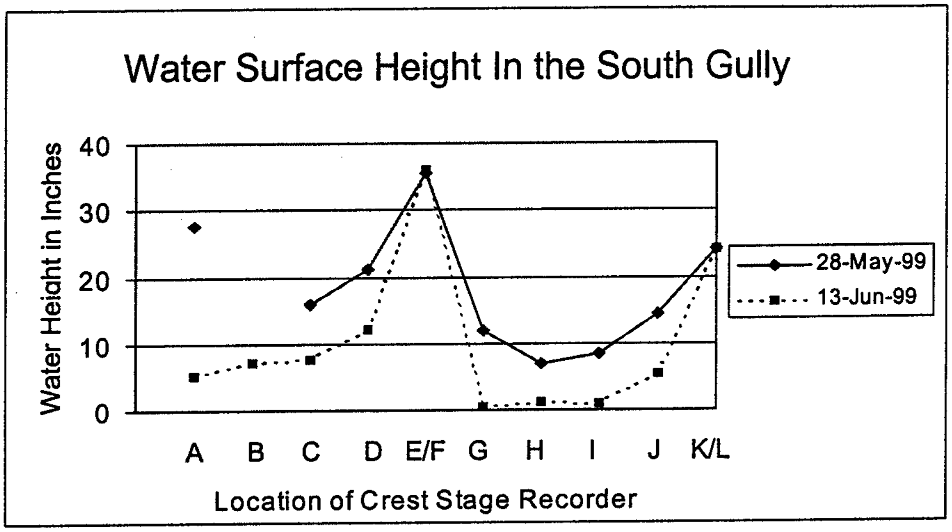


Figure 20. Water surface height in the south gully. Damage to monitoring equipment led to missing data. Water flows downhill from A to L. RCD 2 immediately follows CSR F.

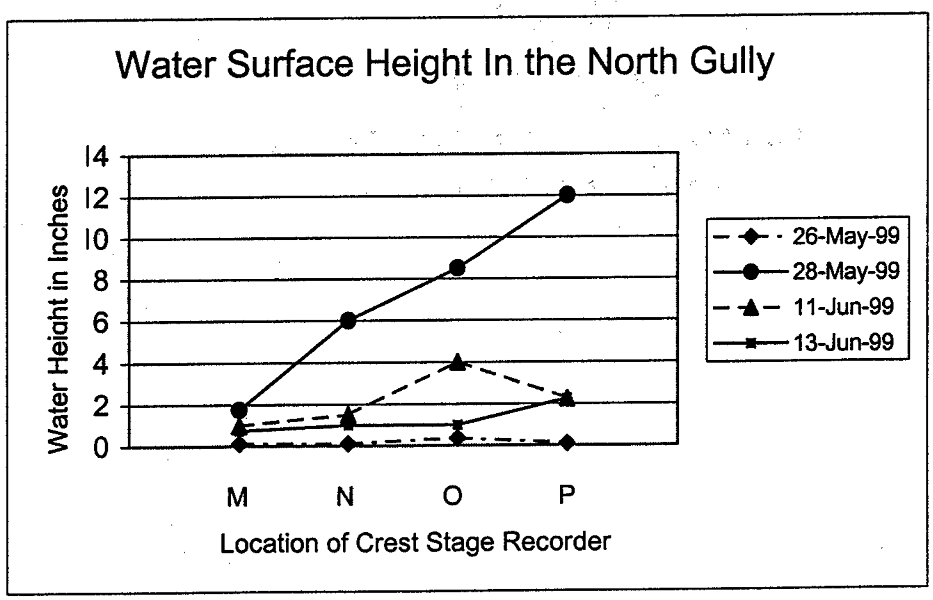


Figure 21. Water surface height in the north gully. Antecedent moisture from May 26 rainfall significantly increased the water height in the gully during the May 28 event. Water flows downhill from M to P.

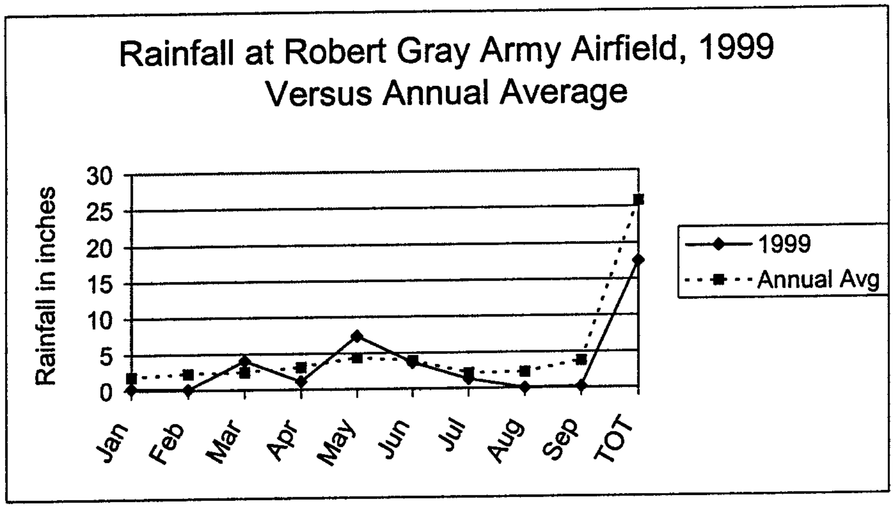


Figure 22. Rainfall data from Robert Gray Army Airfield. Annual average data is compared against rainfall during 1999.

the study period was nearly normal despite a 32 percent (eight inches) shortfall through the month of September.

Figures 23 and 24 illustrate the trends in slope from the top of Antelope Mound to the heads and then to the feet of both gullies. The locations of each instrument and check dam are shown on the figures. The slope from Antelope Mound is 5.8 percent to the head of the south gully, and is 5.7 percent to the head of the north gully. The slope in each gully from head to foot is 1.2 percent. Each gully drainage basin area is approximately 5.3 acres, and the length of overland flow ranges from zero to nearly 1000 feet.

The sediment collection pond west of the study site (Fig. 14) collects all the sediment and stormwater shed by Areas One, Two and Three. The low, submerged zone comprises seventy-four percent of the total area, while a high-ground aerated zone to the south makes up eight percent. The intermediate, intermittently flooded zone between the aerated and submerged areas comprises the remaining eighteen percent.

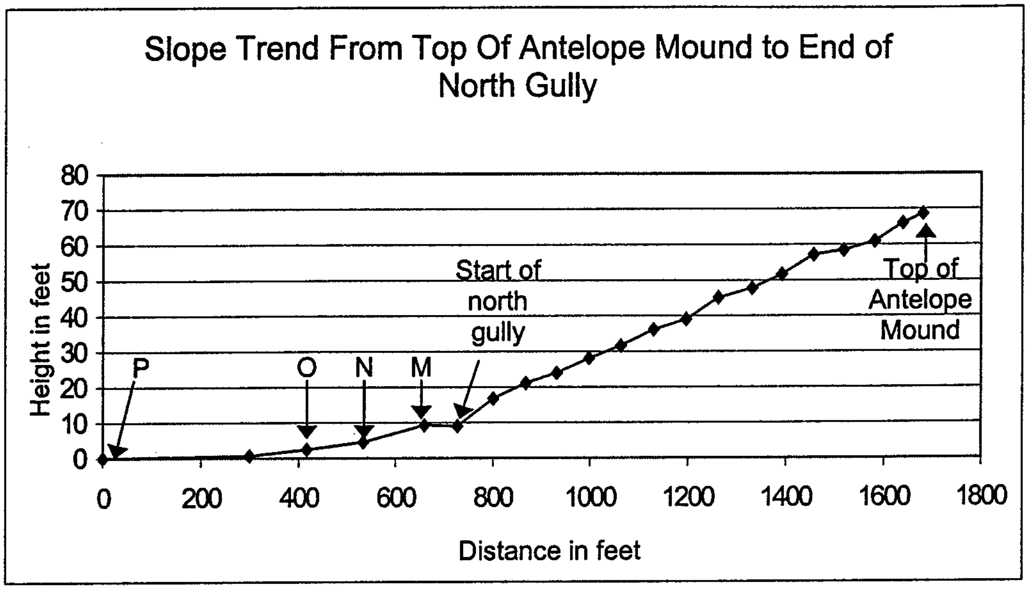


Figure 23. Slope from top of Antelope Mound to end of north gully.

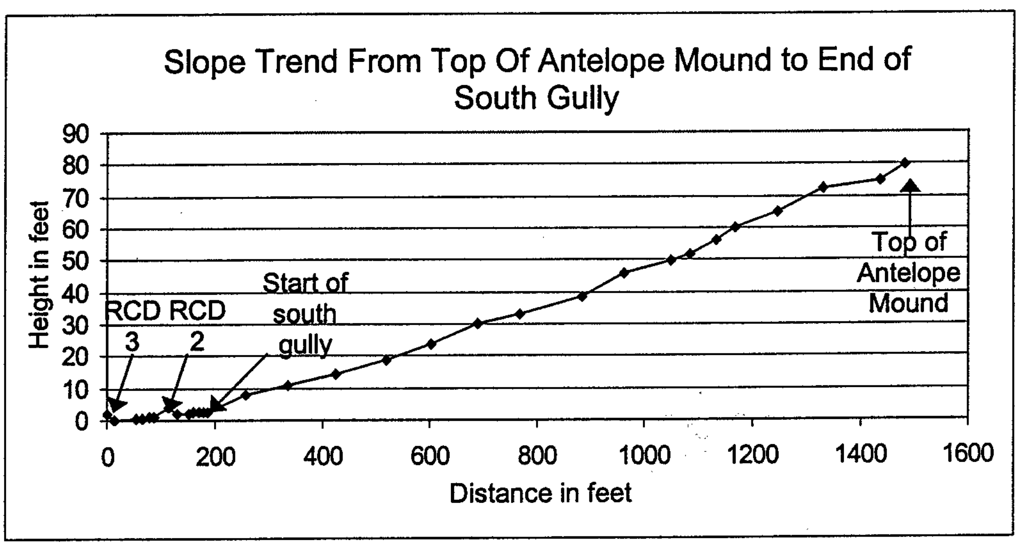


Figure 24. Slope from top of Antelope Mound to end of south gully.

The total area of the pond is 168,900 square feet, or 3.8 acres. The amount of sediment in the structure was estimated at 4242.3 tons in the submerged zone, 2340.0 tons in the intermediate zone, and 472.1 tons in the aerated zone, for a total of 7054.4 tons. The average rate of deposition in the catchment since 1992 from sheet/rill and gully erosion from Areas One, Two and Three is 1007.8 tons per year.

Figure 25 shows the results of the static cone penetrometer tests on the strip of ground near the north gully. The high shear strength readings were taken from areas compressed by tank or other tracked vehicle tracks, while the low-strength readings were taken from areas between the tracks on uncompressed ground. The mean reading value was 3.74, with a low value of 0.01 and a high value of 5.87.

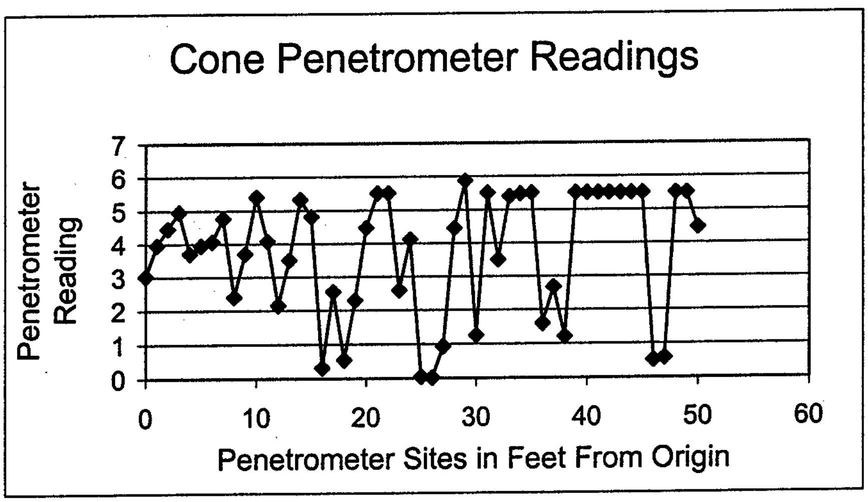


Figure 25. Cone penetrometer readings from test strip near the north gully. High readings indicate tank tracks; low readings are between vehicle tracks.

GIS Analysis

The SWAT hydrologic model was run to estimate sediment output from Area One based on a "southwest rangeland" land cover. The model was run for a five-year period. Run outputs describing basin characteristics and sediment output are shown in Table 2.

Table 2. SWAT hydrologic model output summary.

Output Description	Data
Total basin area (sq km)	0.63
Total basin area (hectares)	63.01
Total basin area (acres)	155.70
Sediment yield in tons/hectare/year	4.60
Total basin sediment yield in metric tons/year	289.80
Sediment yield in tons/acre/year	1.86
USDA allowable soil loss threshold (T) in tons/acre/year	5.00

The allowable annual soil loss per acre for the Slidell soil is 5 tons (McCaleb, 1985), which is well above the model-predicted amount.

The ArcView GIS map analysis using the four criteria of slope, land use, soil hydrologic group and percentage of clay resulted in the map coverage shown in Figure 26. The areas shown in blue depict areas on Fort Hood which have a slope of five to twelve percent. The areas in red met all of the ArcView map query criteria and are the locations most susceptible to gully erosion.

Soil Loss Calculations

The USLE input parameters and the total estimates of sheet and rill erosion for Area One are shown in Table 3. Sheet and rill erosion from the "Low Traffic, High Vegetation" scenario was 211.99 tons per year, which was reduced by a delivery ratio of 0.48 to an actual loss of 101.76 tons per year. The "High Traffic, No Vegetation" scenario resulted in a loss of 1531 tons per year, which was reduced by the same delivery ratio to 734.88 tons per year.

The input parameters and erosion estimates for sheet/rill erosion in Areas Two and Three are shown in Table 4. After application of the same 0.48 delivery ratio, the loss from Area Two is 48.17 tons/year, and the loss from Area Three is 50.53 tons/year.

Figure 26. ArcView map query output map coverage. Areas in blue depict areas with the targeted 5 to 12 percent slope range. Areas in red depict areas on Fort Hood meeting all map query criteria and likely to experience gully erosion

Table 3. USLE input parameters and totals for sheet/rill erosion in Area One.

Low Traffic, High Vegetation				
	Zone 1	Zone 2	Zone 3	Zone 4
USLE Factor	Plant Cover	Plant Cover	Plant Cover	Plant Cover
R	280.00	280.00	280.00	280.00
K	0.32	0.32	0.32	0.32
LS	0.25	1.80	0.15	2.00
C	0.10	0.10	0.10	0.10
P	1.00	1.00	1.00	1.00
A	2.24	16.13	1.34	17.92
acres in zone	12.60	4.90	12.60	4.90
soil loss in zone (tons)	28.22	79.03	16.93	87.81

Soil loss (tons/Area One/year)	211.99
Delivery ratio	0.48
Total loss (tons/Area One/year)	101.76

High Traffic, No Vegetation				
	Zone 1	Zone 2	Zone 3	Zone 4
USLE Factor	Plant Cover	No Plant Cover	Plant Cover	No Plant Cover
R	280.00	280.00	280.00	280.00
K	0.32	0.32	0.32	0.32
LS	0.25	1.80	0.15	2.00
C	0.25	0.85	0.25	0.85
P	1.00	1.00	1.00	1.00
A	5.60	137.09	3.36	152.32
acres in zone	12.60	4.90	12.60	4.90
soil loss in zone (tons)	70.56	671.73	42.34	746.37

Soil loss (tons/Area One/year)	1531.00
Delivery ratio	0.48
Total loss (tons/Area One/year)	734.88

Table 4. USLE input parameters and totals for sheet/rill erosion in Areas Two and Three.

Area Two	
Factor	Value
R	280.00
K	0.32
LS	0.20
C	0.20
P	1.00
A	3.58
Acres in area	28.00
Soil loss in area (tons)	100.35
Delivery ratio	0.48
Total loss (tons/area/year)	48.17

Area Three	
Factor	Value
R	280.00
K	0.32
LS	0.25
C	0.10
P	1.00
A	2.24
Acres in area	47.00
Soil loss in area (tons)	105.28
Delivery ratio	0.48
Total loss (tons/area/year)	50.53

The final estimates of sheet/rill and gully erosion for all three areas are shown in Table 5. The total annual loss from the study area due to sheet/rill erosion is 833.58 tons. After application of a 0.70 delivery ratio to the initial gully outputs, annual loss from gully erosion is 161.7 tons in Area One, 215.6 tons in Area Two, and 10.78 tons in Area Three, for a total loss from the study area of 388.08 tons per year. Total combined annual loss due to sheet/rill and gully erosion are 896.58 tons in Area One, 263.77 tons in Area Two, and 61.31 tons in Area Three, for a total loss from all sources of 1221.66 tons per year. Sheet/rill erosion comprised 68.2 percent of total annual erosion loss, and gully erosion contributed the remaining 31.8 percent.

Table 5. Annual sediment outputs by type and area.

Annual Sediment Output Summary In Tons				
Type of Erosion	Area One	Area Two	Area Three	Total
Sheet/Rill	734.88	48.17	50.53	833.58
Gully	161.70	215.60	10.78	388.08
Total	896.58	263.77	61.31	1221.66
			Grand total	1221.66

CHAPTER FOUR

Discussion

Field Monitoring and Lab Testing

Deposition dominated in the south gully (Fig. 15) and scour dominated in the north gully (Fig. 16). Due to the relatively small size of the south gully and its low channel slope (1.2%), the area of influence of the check dams extends upslope for a considerable distance. After the May 28 and June 16 rainfall events, stormwater that did not overtop the check dams pooled upslope from them for approximately ten days. Most stormwater pooled within 20 feet of each dam, where deposition of suspended sediment was most pronounced. The reason for the long detention time behind the structures was due to the clay soil core in each dam and its very low permeability (McCaleb, 1985). This core is not typical of rock check dam design, which is generally intended to pass stormwater through while causing sediment to drop out.

The source of the sediment deposited at the check dams was a combination of sediment removed from the banks by rainsplash, and to a lesser extent, channel bed sediment. Evidence of rainsplash erosion (Ellison, 1948) was indicated by a small reduction of the gully banks in cross section measurements. A very slight (unmonitored) amount of sediment moved downstream over the top of the check dams.

There was essentially no new channel erosion or gully head movement in the south gully. The check dams divided the gully into short segments which acted as separate elongated ephemeral ponds, so water moving in the bottom of the gully moved for only 25-30% of the distance previously possible before encountering a check dam.

South gully head movement was stopped entirely. This was partly due to the presence of the first check dam (RCD 1), which was approximately 20 feet from the gully head (Fig. 6) and caused stormwater to pond and prevented concentrated channel flow. Also, tracked vehicles drove over the gully head stake in July and flattened the area for 50 feet upslope. This traffic compacted the soil surface but did not remove the vegetation and further minimized continued head movement or new incision.

Scour was the net dominant process at sites M, N and O in the north gully, and resulted primarily from sidewall erosion. The more resistant Walnut Clay bedrock is occasionally exposed in the gully bottom, forcing water moving through the gully to spread laterally and undercut the banks (Carson, 1971). Bank failure at sites M and O lowered the amount of net scour at the sites. Loose, scattered platy limestone cobbles in the gully at and near site P protect the gully floor against erosion. Site P is 100 feet west of the north-south dirt road shown in Figure 6 and is nearly flat. Traffic on the road mechanically weathers the soil, increasing erosion and sediment entrainment (Bircket, 1993). The gully width at site P is 150 percent wider than at sites M, N and O, and this increased area and low slope caused greater deposition.

The north gully headwall moved upslope 7.8 inches during the monitoring period. All movement occurred from mid-April to mid-June due to generally normal rainfall. The movement was aided by a large amount of tank traffic upslope from the gully during the study period. This traffic increased bulk density (Bircket, 1993) and soil compaction beginning approximately 50 feet upslope from the gully head, and extended to the top of Antelope Mound, increasing surface runoff and allowing faster gully growth.

Sediment loss from the north gully is estimated at 44.13 cubic yards per year. The monitored length of the south gully is 72 percent shorter than the monitored length of the north gully. Increasing the estimated sediment output from the south gully by an equivalent amount results in a total output of 34 cubic yards per year for an equivalent length of the south gully. Therefore, the processes operating in both gullies are relatively similar, with two primary differences. The first is that the south gully is dammed and channel erosion is greatly reduced, while stormwater in the north gully moves freely and has greater power. The second difference is that the Walnut Clay bedrock is exposed in the bottom of the north gully but not in the south gully, causing faster water movement, increased scour and higher sediment output from the north gully.

Only three months (April 14 to July 23) were required to deposit the sediment found at RCD 2 (1.27 cubic yards) and RCD 3 (1.92 cubic yards), resulting from rainfall that was eight inches and 68 percent below average for the year, but was at nearly normal levels during the monitoring period (April 1999 to September 1999). This rate of fill projected over a twelve-month period results in 137.6 cubic feet of fill at RCD 2, and 207.36 cubic feet at RCD 3. With normal rainfall and no change in land use, the check dams will be overtopped with sediment in three years, ending their effective design lifespan. Check dams installed in other areas with similar gully erosion problems may have different lifespans based on the characteristics of the site being controlled, however.

The high rate of deposition in the dammed south gully versus the high rate of scour from the natural, undammed north gully shows that the check dam method of sediment control is extremely effective at reducing gully erosion and sediment transport. The net effect at the check dams is that sediment moved by sheetwash or rainsplash or

short channel flow enters the south gully, but is effectively trapped at the dams, passing only in stormwater overtopping the dams. The two dams together trapped 86.24 cubic feet of sediment during the study period, for an estimated annual rate of 9.6 cubic yards per year, indicating that check dams can significantly aid the military installation erosion control program. Continued though lessened check dam effectiveness can be assumed beyond the point at which the dam is overtopped by sediment, since the dammed sediment will create an area of very low slope, preventing downcutting due to the lack of channel flow, and causing continued deposition due to channel irregularity and low slope.

The study was conducted during typical peak summer training times and the months with the normally highest rates of precipitation. Training on Fort Hood occurs year-round, but increases during the summer. When this increased traffic is compounded with high rates of rainfall, significant damage to the landscape can occur. The rate of training was high during this study, but the average interval between rain events was nine days, with the last event occurring on June 16. With more frequent rainfall providing more moisture in the top layer of soil, the effects on the landscape and the increase in erosion would be significantly higher than the effects shown during this study.

The sediment concentration data shown in Figures 17 and 18 showed that the lowest bottles at all SSRs had the highest concentrations, due to their longer exposure to the sediment-laden water. Sediment concentration generally decreased as the height of the bottle increased, indicating shorter exposure to stormwater. The concentrations at SSRs 1 and 2 were higher than at SSRs 3 and 4, indicating that sediment which would have normally moved past the location of SSRs 3 and 4 was trapped at RCD 2 and recorded at SSRs 1 and 2. The concentrations in the lower bottles at SSRs 5 and 6 in the

north gully were very high, indicating no sediment control and free sediment movement. The top bottles at SSRs 5 and 6 were never completely filled, since there were no check dams to cause pooling of stormwater as occurred in the south gully.

The grain size distribution data (Fig. 19) show that the D_{50} grain sizes ranged from medium to fine silt, indicating large amounts of fine-grained sediment present in the stormwater, as is normally found after land degradation (Nawrocki, 1976).

The water surface height data shown in Figures 20 and 21 dramatically demonstrated the effects of antecedent moisture on the behavior of the clayey soils and the increase in surface runoff (Richards and Middleton, 1978). There were three rain events in May, occurring on the 10^{th} (1.94 inches), 26^{th} (0.73 inch) and 28^{th} (1.04 inches). North gully crest stage recorder measurements after the May 26 event reflect a very low water surface height at all locations (0.1 inch to 0.36 inch). The May 28 event caused significantly higher water surface heights (1.75 inches to 12 inches), indicating increased surface runoff in the clay-rich soil following the rain event two days earlier. The average height increase was 6.9 inches, and ranged from 1.62 inches at site M to 11.9 inches at site P. Data from the south gully is incomplete and could not be evaluated in this manner.

The strip of land tested with the cone penetrometer demonstrated the effects of heavy vehicle traffic on soil compaction and shear strength (Fig. 25). The points showing the lowest shear strength were between vehicle track paths and the soil was furrowed and disturbed, reducing soil strength and cohesiveness (Bircket, 1993). The highest-strength points lay in vehicle tracks and were highly compacted. This compaction causes reduced water infiltration and increased surface runoff. The resultant heterogeneity of the soil

leads to immediate increased erosion of the disturbed areas and forms a barrier to the growth of new vegetation in the compacted areas, leading to increased erosion in the future.

The primary factor which led to the formation of the gully network, despite the type of land use remaining constant, was the increase in the land use intensity (vehicle traffic), which caused a dramatic loss of the natural vegetative cover. This loss caused greatly increased surface runoff, decreased infiltration, and increased rates of sheet, rill and finally gully erosion, which resulted in the large gully systems present today, dramatically illustrating the importance of vegetation in determining the rate of erosion (Reid, 1969). Areas which experience a change in land use, usually due to site degradation as in road construction, almost always experience gullying, especially in low-permeability soils. This sequence of events occurred to a large degree in the study area, and resulted in the extensive system of gullies which are dangerous to vehicle traffic and cause heightened soil loss.

There are several possibilities as to why the heads of both gullies begin at essentially the same distance from the top of Antelope Mound. One is that the long overland flow distance allows stormwater to accumulate to a great enough depth to generate the tractive force needed to detach sediment (Morgan, 1986). Another possibility is that since the gully heads are at the junction between soils with significantly different amounts of clay, the reduced infiltration and increased runoff caused by the lower clay-rich soil leads to gully formation. A third possibility is that the overland flow at the gully head locations is of longer duration than elsewhere, since the flow will continue until all overland flow from the mound ceases. This more continuous flow

would lead to greater incision. Still another possibility is that any gullies that form on the slopes or that have formed in the past have been destroyed and mixed or assimilated back into the soil as a result of vehicle traffic. The lack of headward erosion in the south gully demonstrated this, as the vehicle traffic began at the head of the gully and continued upslope, preventing continued gully incision or formation.

GIS Analysis

Soil erosion estimates from the SWAT model run are compared to the USLE calculations of soil loss in the "Soil Loss Calculations" section later in this chapter.

The process of physical characteristic identification and ArcView map query required considerable trial and error. Even when using several criteria, there were many locations identified as having the potential for gully erosion. The amount of area having steep slopes due to very hard bedrock exposures in the north sections of Fort Hood is the primary reason. A source of error in the analysis is the separate digitized Bell and Coryell county SSURGO map layers, which do not precisely edge-match and do not precisely reflect soil extents. Another source of error is the inherent error in the three-meter resolution DEM provided by Fort Hood which was used throughout GIS processing. The installation slope map coverage which ArcView derived from the DEM indicated that the program calculated the slope of Antelope Mound at 3.8 percent, which is 65 percent of its actual slope.

The ArcView analysis nevertheless generated a successful product, in that the locations indicated by the GIS output (Fig. 26) agreed with the actual locations of gullies at 20 of 21 sites (95 percent) visited during site reconnaissance. Five sites were steep hills, had one to two access roads to the top of the hill, and very little other site

disturbance. At these sites gullies were only present in association with the access roads. There were no gullies at one site, likely due to the lack of ground disturbance at the site.

Soil Loss Calculations

The USLE and SWAT erosion estimates show that erosion is and will remain a significant problem. Calculation of sheet and rill erosion from Area One using the USLE resulted in a projected sediment loss of 101.76 tons per year in idealized low-traffic and high vegetation conditions, and 724.04 tons per year in the current high-traffic and low to absent vegetation conditions. The wide disparity in output between subzones in Area One was expected, given the large difference in soil erodibility between the vegetated and devegetated states. The difference in slope was not a major factor in the projection of soil loss, but the difference in land cover due to the total loss of vegetation from Antelope Mound was very significant, causing a 612 percent increase in the overall loss rate. The smaller amounts of sheet and rill erosion estimated for Areas Two and Three were due to their relatively low slope and year-round vegetation coverage.

The SWAT model predicted a sediment loss rate that was 36 percent lower than the USLE estimate. The USLE predicted a soil loss of 101.76 tons per year for Area One during low traffic and high-vegetation conditions, while the SWAT model estimated annual loss at 65.1 tons. The difference is likely due to incomplete rainfall data and full vegetative cover conditions used by SWAT. SWAT filled gaps in the incomplete rainfall input file by simulating daily rainfall. The model's simulated annual rainfall was 23.49 inches per year, well below the area's 34.2-inch annual average. Increasing the SWAT erosion estimate by an equivalent percentage resulted in 94.8 tons per year, agreeing well with the value estimated with the USLE. Also, SWAT was run with simulated rangeland

vegetation over the entire area, in contrast to the estimated 70 percent coverage actually on the site. Increasing the SWAT erosion estimate to account for the difference in vegetative consideration by the model and the USLE would further align the estimates.

Bircket's (1993) study of erosion on Fort Hood estimated that sheet and rill erosion constituted 42.9 percent of overall erosion on the installation, with 9.3 percent resulting from gully erosion. The 1993 estimates for this specific study area indicated that 44.6 percent of total erosion was due to sheet and rill erosion, gully erosion comprised 8.2 percent, and the total annual loss was 1103 tons.

The monitored rates of gully scour and estimates of sheet and rill erosion in this study indicate that sheet and rill erosion comprise 68 percent of the total annual sediment loss of 1221.66 tons, with gully erosion comprising the remaining 32 percent. This rate of gully erosion is more than triple the installation average (Bircket, 1993), indicating that the problem of gully erosion is a localized but significant problem, and that gully erosion at the study site has increased considerably since 1993.

The difference between the rates of gully scour and deposition between the monitored gullies show the effectiveness of the check dams in controlling erosion. Assuming check dam trap efficiency remains at 95 percent for at least three years, installation of check dams in all of the study site gullies can reduce annual gully erosion loss from the current 388 tons to 368 tons. This would reduce the amount of total erosion by 30 percent, and would considerably extend the lifespan of the sediment catchment.

Check dam cost-effectiveness is dependent on their lifespan and their contribution to site improvement. Their lifespan in this location is approximately three years, but as discussed earlier, remnant effects may considerably extend their erosion-reduction

lifespan. The average cost of $500 per dam is offset by the increase in safety to vehicle traffic through the area, the nearly total blockage of gully sediment loss for at least three years, and the extension of the usefulness of the sediment catchment for at least three years.

The amount of sediment found in the catchment was 7054.4 tons, while the amount predicted to have eroded into it since 1992 was 8551.62 tons. The predicted amount was 17.5 percent greater than the amount found, which is similar to the 7721 tons estimated by Bircket (1993). The variance between the 1999 and 1993 erosion estimates is likely due to an increase in gully size and general site degradation since 1993.

The accelerated rate of sheet and rill erosion in the study area will continue to remove soil until the bedrock is exposed. This rate is highest in Zones Two and Four of Area One (the top of Antelope Mound), at 680 tons per year from the two zones. Assuming soil density of 90.5 pcf and no erosion control measures, the zones will lose at least 0.42 inches of topsoil every year. The minimum thickness of the soil covering the mound was 34 inches (McCaleb, 1985) in 1985. A test hole bored in a tire-track depression on top of the mound showed only twelve inches of highly compacted soil, however, indicating a localized rate of erosion on the summit of the mound nearly 300% greater than the expected rate. Local microrelief elevation varies by up to three feet.

If the current type and rate of usage continues unchanged, most soil will be lost from the top of the mound in approximately 18 years, exposing large areas of Walnut Clay bedrock. Exposing bedrock to vehicle traffic will essentially eliminate the possibility of vegetation reestablishing itself, and erosion will continue with bedrock as an additional source of sediment.

The study area loses 1000 cubic yards of sediment per year in total erosion. Ten years of soil loss from the study area will result in 10,000 cubic yards of eroded sediment, which equates to eighteen feet of sediment on a football field-size area, and is produced from a watershed which comprises 0.05 percent of the total area of Fort Hood. This high rate of erosion leads to the problem of sediment accumulation in the sediment catchment and in the gullies at the check dams. The check dams will be overtopped in three years in this watershed with no change in overall erosion control, and the sediment catchment will also eventually fill. Once the catchment has filled with sediment, its effective lifespan is over and it must be enlarged or the accumulated sediment must be removed. The current plan is to remove the sediment and renew the catchment. This course of action will entail identification of a destination for the sediment and considerable cost to remove the sediment, transport it, and emplace it at its new location, which could consist of stockpiling it, spreading it, or using it as fill material in other gully systems. Sediment at the check dams will not be removed from the gully systems.

Emplacing additional check dams in the undammed study area gullies, and implementing sheet erosion controls on Antelope Mound such as terraces, infiltration strips, and interception ditches, would significantly decrease the rates of gully and sheet erosion, allow vegetation to recover, and increase the lifespan of the sediment catchment. If no erosion control is applied to the area, existing check dam effectiveness will decrease after three years, the undammed gullies will continue to erode without control, and sheet erosion will continue unchecked. Therefore, the emplacement of sheet erosion controls and two check dams in each undammed study area gully is highly recommended. Failure

to provide erosion control practices and structures will result in increased rates of erosion and gully formation and growth.

The results of this study agree closely with the estimates from the 1993 Fort Hood erosion study, and indicate that the processes have remained constant over time, but the gully erosion problem has worsened slightly since 1993, leading to increased gully size and sediment contribution.

Other problems and sources of error associated with this study included human activity in the area, including theft and destruction of monitoring equipment. Stage sediment recording bottles and rain gauges were stolen, crest stage recorders were tampered with, and persons walked down the gully channel to look more closely at the instruments. The resulting deep footprints caused difficulty in accurately measuring channel geometry. There were occasionally deep animal tracks in the bottoms of the gullies, which disrupted the natural gully formation process and occasionally destroyed monitoring equipment.

Recommendations for further study in this area include emplacement of Borros points for at least a two-year period to determine the different rates of ground loss at different locations in the study area. Another recommendation is to emplace varying methods of erosion control on the bare surface of Antelope Mound and monitor their effectiveness over at least a twelve-month period. A final recommendation is to utilize the drainage basin area and critical slope method described in the introduction chapter of this paper to analyze a larger area of Fort Hood and create an empirical formula for a subsequent GIS analysis of the entire installation. The NRCS is currently working to resolve the issue of soil characteristics agreement between Coryell and Bell counties, but

the issue of creating digitized soil layers for the two counties that do edge-match still remains and requires repair.

CHAPTER FIVE

Conclusions

The study was successful in meeting its three primary objectives. The rates of sheet and rill erosion, gully erosion, and total erosion in the study area were quantified and compared to the actual amount of sediment collected in the study area's sediment catchment. The two amounts differed by only 17.5 percent, which is an acceptable degree of correlation for such a complex system. Estimates of sediment loss and collection agree closely with the 1993 erosion study done on the same area, and indicate an increase in overall gully erosion and sediment loss since 1993.

Rock check dams were found to be highly effective, with a likely trap efficiency of over 95 percent for the monitored system of three check dams per gully. The effective lifespan for similar structures in similar settings was estimated at three years, and longer for structures in areas with less overall erosivity. Remnant effects will continue to provide limited erosion control for some time after the end of the initial effective lifespan. It is therefore feasible and desirable to emplace sediment control structures of this type in those locations deemed suitable by the Fort Hood land managers.

The conditions that produced the gully erosion problem were identified and used in a GIS query to successfully identify similar erosion-prone areas on Fort Hood. Site reconnaissance of the GIS-projected sites resulted in a 95 percent correlation rate. Fort Hood land managers can utilize the map coverage in assessing the problem of gully erosion on the installation.

APPENDICES

APPENDIX A

Fort Hood Personnel, Area and Equipment Information

Table A1. Detailed information on Fort Hood personnel, area and equipment.

Personnel	Military	Others	Total
	40,884	29,657	70,541
Area	Total Area		Vehicle Maneuver Area
	214,351 acres		138,940 acres
	335 square miles		217 square miles
Vehicles	Tracked Vehicles		Wheeled vehicles
	1879		10219

APPENDIX B

Diagrams and Photos of Field Measurement Tools and Equipment

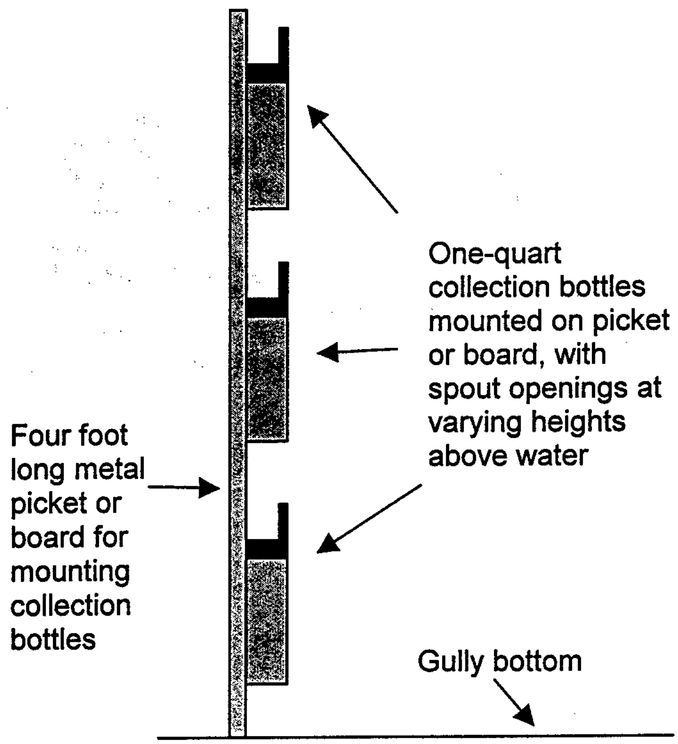


Figure B1. Diagram of stage sediment recorder (SSR) and sample bottles used in monitored gullies.

Table B1. Heights of stage sediment recorder sample bottles at all locations.

Item	South Gully				North Gully	
Crest Stage Recorder	1	2	3	4	5	6
Height of top CSR bottle (inches)	24	16	12	25	22	16
Height of middle CSR bottle (inches)	12	10	8	15	15	12
Height of bottom CSR bottle (inches)	8	7	6	6	8	8

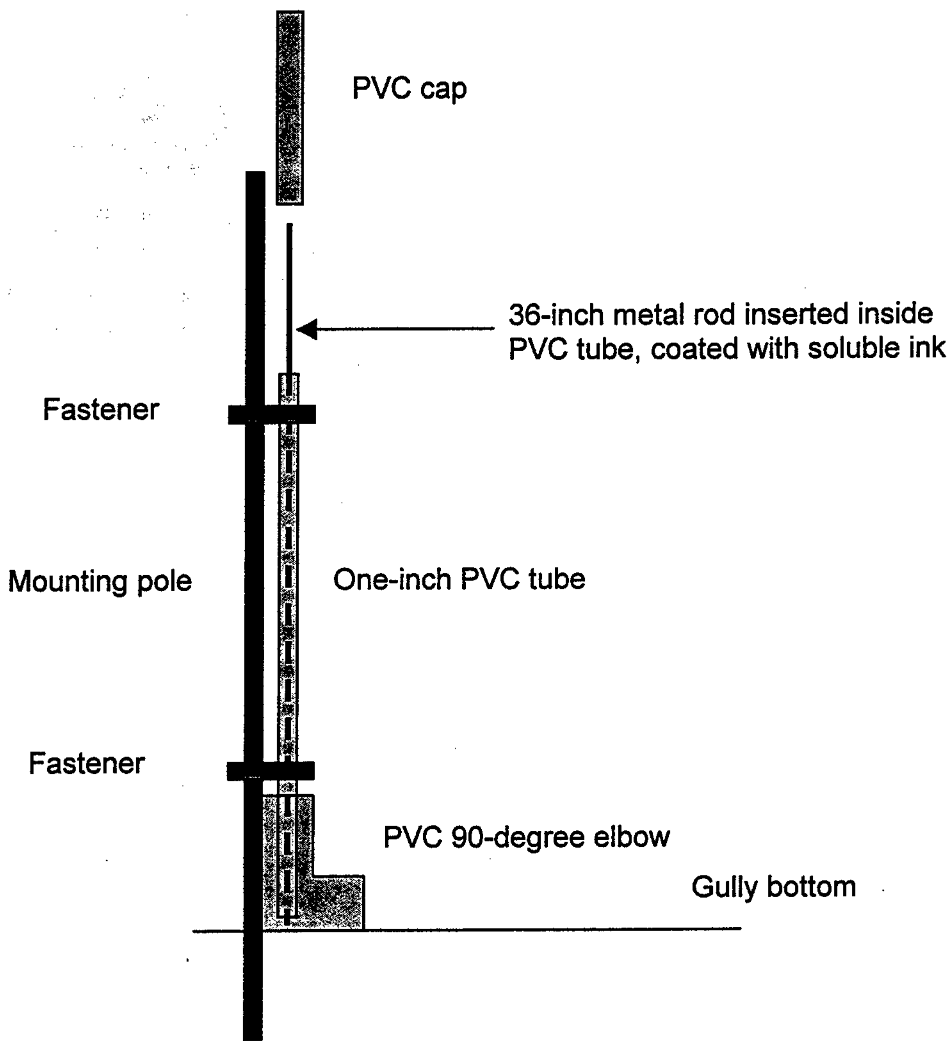


Figure B2. Diagram of crest stage recorder (CSR) used in monitored gullies.

APPENDIX C

Collected Field Data Measurements

This appendix includes all collected field data measurements. The data are in Microsoft Excel format, and are shown in the following order:

1. Cross section data from the south gully
2. Cross section data from the north gully
3. Sediment concentration data
4. Grain size distribution data
5. Water surface height data
6. Survey data from Area One
7. Survey data from the sediment catchment
8. Cone penetrometer data

Table C1a. Cross section data from RCD Two in the south gully. Measurements are in feet, and taken from left to right, looking downgully. A, B, C and D are the cross-section lines at sixteen, twelve, eight and four feet from the check dam, respectively.

		0'	2'	4'	6'	8'	10'	12'	14'	16'	18'
14-Apr-99	A	0	-0.46	-1.75	-3.53	-4.57	-4.48	-3.38	-1.50	-0.16	0
	B	0	-0.18	-0.27	-1.69	-4.15	-4.29	-3.07	-0.78	-0.21	0
	C	0	-0.29	-0.68	-2.09	-3.88	-4.58	-3.71	-2.18	-0.18	0
	D	0	-0.16	-1.17	-2.83	-4.12	-4.40	-3.35	-2.04	-0.24	0
2-May-99	A	0	-0.42	-1.88	-3.38	-4.38	-4.53	-3.46	-1.54	-0.13	0
	B	0	-0.18	-0.29	-2.72	-4.13	-4.23	-3.03	-1.00	-0.21	0
	C	0	-0.29	-0.67	-2.21	-3.95	-4.49	-3.67	-2.12	-0.17	0
	D	0	-0.13	-1.08	-2.68	-4.08	-4.41	-3.53	-2.10	-0.25	0
17-May-99	A	0	-0.36	-1.90	-3.42	-4.29	-4.33	-3.35	-1.54	-0.14	0
	B	0	-0.17	-0.21	-2.54	-3.93	-4.03	-3.14	-1.48	-0.21	0
	C	0	-0.28	-0.67	-2.17	-4.08	-4.31	-3.54	-1.94	-0.13	0
	D	0	-0.13	-0.93	-2.63	-4.03	-4.25	-3.33	-1.83	-0.25	0
27-May-99	A	0	-0.35	-1.60	-3.30	-4.15	-4.11	-3.28	-1.50	-0.14	0
	B	0	-0.15	-2.40	-2.50	-3.80	-3.93	-3.03	-1.55	-0.15	0
	C	0	-0.28	-0.70	-2.20	-3.90	-4.13	-3.40	-2.20	-0.15	0
	D	0	-0.13	-1.20	-1.75	-4.00	-4.16	-3.30	-1.65	-0.31	0
7-Jun-99	A	0	-0.36	-1.70	-3.15	-3.83	-4.00	-3.25	-1.48	-0.14	0
	B	0	-0.15	-0.30	-2.42	-3.73	-3.83	-3.06	-1.45	-0.15	0
	C	0	-0.27	-0.73	-2.18	-3.78	-4.06	-3.36	-2.00	-0.12	0
	D	0	-0.12	-1.10	-2.65	-3.90	-4.10	-3.35	-1.80	-0.26	0
9-Jul-99	A	0	-0.28	-1.80	-3.17	-3.75	-3.85	-3.25	-1.45	-0.14	0
	B	0	-0.30	-0.80	-2.55	-3.70	-3.78	-3.05	-1.52	-0.15	0
	C	0	-0.27	-0.72	-2.10	-3.64	-3.83	-3.25	-1.95	-0.12	0
	D	0	-0.12	-1.00	-2.51	-3.75	-3.90	-3.24	-1.77	-0.26	0
12-Jul-99	A	0	-0.35	-1.90	-3.18	-3.66	-3.85	-3.15	-1.45	-0.20	0
	B	0	-0.30	-0.80	-2.50	-3.65	-3.73	-2.90	-1.50	-0.15	0
	C	0	-0.27	-0.72	-2.30	-3.65	-3.85	-3.23	-2.00	-0.15	0
	D	0	-0.12	-0.93	-2.48	-3.73	-3.91	-3.24	-1.67	-0.24	0
14-Jul-99	A	0	-0.25	-1.72	-3.13	-3.67	-3.88	-3.18	-1.45	-0.20	0
	B	0	-0.30	-0.65	-2.50	-3.66	-3.78	-3.03	-1.47	-0.15	0
	C	0	-0.27	-0.72	-2.07	-3.63	-3.83	-3.25	-1.92	-0.15	0
	D	0	-0.12	-0.95	-2.50	-3.77	-3.89	-3.28	-1.66	-0.24	0
23-Jul-99	A	0	-0.37	-1.80	-3.12	-3.65	-3.83	-3.18	-1.60	-0.20	0
	B	0	-0.30	-0.70	-2.51	-3.60	-3.75	-3.00	-1.45	-0.15	0
	C	0	-0.27	-0.76	-2.01	-3.64	-3.88	-3.48	-2.25	-0.15	0
	D	0	-0.12	-0.98	-2.52	-3.72	-3.89	-3.23	-1.80	-0.24	0

Table C1b. Cross section data from RCD Three in the south gully. Measurements are in feet, and taken from left to right, looking downgully. A, B, C and D are the cross-section lines at sixteen, twelve, eight and four feet from the check dam, respectively.

		0'	2'	4'	6'	8'	10'	12'	14'	16'	18'
14-Apr-99	A	0	-0.17	-1.90	-3.54	-4.69	-3.71	-1.21	-0.54	-0.13	0
	B	0	-0.21	-1.67	-3.41	-4.35	-4.40	-2.71	-1.16	-0.28	0
	C	0	-0.08	-0.33	-2.69	-4.38	-4.79	-3.38	-1.61	-0.15	0
	D	0	-0.45	-1.00	-2.63	-3.35	-3.67	-3.55	-2.62	-0.39	0
2-May-99	A	0	-0.16	-1.90	-3.57	-4.50	-3.83	-1.19	-0.53	-0.15	0
	B	0	-0.21	-1.69	-3.40	-4.38	-4.40	-2.60	-1.15	-0.28	0
	C	0	-0.08	-0.33	-2.65	-4.40	-4.50	-3.41	-1.59	-0.17	0
	D	0	-0.45	-1.05	-2.68	-3.71	-3.50	-3.57	-2.75	-0.38	0
17-May-99	A	0	-0.17	-2.00	-3.50	-4.47	-4.00	-1.21	-0.53	-0.17	0
	B	0	-0.18	-1.63	-3.42	-4.50	-4.38	-2.50	-1.00	-0.23	0
	C	0	-0.08	-0.32	-2.63	-4.58	-4.50	-3.50	-1.58	-0.17	0
	D	0	-0.45	-1.04	-2.78	-3.67	-3.71	-3.59	-2.67	-0.38	0
27-May-99	A	0	-0.15	-1.95	-3.50	-4.40	-3.95	-1.30	-0.60	-0.13	0
	B	0	-0.20	-1.60	-3.40	-4.33	-4.30	-2.40	-1.00	-0.23	0
	C	0	-0.08	-0.35	-2.53	-4.20	-4.50	-3.60	-1.65	-0.20	0
	D	0	-0.45	-1.03	-2.75	-3.55	-3.60	-3.60	-2.70	-0.35	0
7-Jun-99	A	0	-0.15	-1.90	-3.38	-4.25	-3.85	-1.27	-0.60	-0.14	0
	B	0	-0.20	-1.60	-3.41	-4.28	-4.25	-2.44	-1.25	-0.20	0
	C	0	-0.08	-0.32	-2.50	-4.05	-4.25	-3.35	-1.65	-0.20	0
	D	0	-0.45	-1.05	-2.60	-3.52	-3.50	-3.65	-2.80	-0.35	0
23-Jul-99	A	0	-0.10	-1.80	-3.40	-4.12	-3.55	-1.25	-0.60	-0.14	0
	B	0	-0.20	-1.65	-3.37	-4.24	-4.03	-2.33	-1.02	-0.20	0
	C	0	-0.08	-0.32	-2.45	-4.03	-4.15	-3.18	-1.65	-0.20	0
	D	0	-0.46	-1.04	-2.60	-3.22	-3.35	-3.40	-2.70	-0.35	0

Table C2a. Cross section data from Site M in the north gully. Measurements are in feet and taken from left to right, looking downgully.

	0'	2'	4'	6'	8'	10'	12'	14'	16'	18'	20'	22'
18-Apr-99	0	-0.15	-1.40	-3.25	-3.57	-3.60	-3.70	-3.77	-3.97	-0.58	-0.15	0
2-May-99	0	-0.15	-1.42	-3.04	-3.53	-3.57	-3.53	-3.67	-3.77	-0.58	-0.15	0
11-May-99	0	-0.33	-1.43	-3.17	-3.58	-3.45	-3.46	-3.79	-3.96	-0.54	-0.15	0
27-May-99	0	-0.18	-1.50	-3.18	-3.50	-3.37	-3.58	-3.90	-3.95	-0.60	-0.15	0
7-Jun-99	0	-0.23	-1.41	-3.21	-3.51	-3.50	-3.55	-3.75	-3.93	-0.60	-0.15	0
13-Jun-99	0	-0.20	-1.42	-3.15	-3.50	-3.40	-3.55	-3.72	-3.93	-1.05	-0.15	0
16-Jun-99	0	-0.15	-1.43	-3.10	-3.48	-3.45	-3.47	-3.71	-3.96	-1.90	-0.15	0
9-Jul-99	0	-0.28	-1.70	-3.23	-3.52	-3.44	-3.55	-3.63	-3.78	-3.10	-0.15	0
12-Jul-99	0	-0.25	-1.48	-3.13	-3.50	-3.41	-3.53	-3.63	-3.70	-3.02	-0.15	0
14-Jul-99	0	-0.25	-1.60	-3.20	-3.50	-3.40	-3.53	-3.64	-3.70	-3.00	-0.15	0
23-Jul-99	0	-0.16	-1.18	-2.78	-3.48	-3.40	-3.42	-3.56	-3.76	-3.49	-0.15	0
15-Aug-99	0	-0.22	-1.28	-2.80	-3.50	-3.42	-3.50	-3.56	-3.70	-3.38	-0.15	0

Table C2b. Cross section data from Site N in the north gully. Measurements are in feet and taken from left to right, looking downgully.

	0'	2'	4'	6'	8'	10'	12'	14'	16'	18'	20'
18-Apr-99	0	0	-0.50	-1.64	-2.81	-5.94	-6.63	-1.25	-0.31	-0.10	0
2-May-99	0	0	-0.50	-1.46	-2.69	-6.13	-6.60	-1.25	-0.31	-0.10	0
11-May-99	0	0	-0.50	-1.44	-2.68	-6.17	-6.70	-1.50	-0.23	-0.10	0
27-May-99	0	0	-0.50	-1.50	-2.74	-6.30	-6.68	-1.69	-0.23	-0.10	0
7-Jun-99	0	0	-0.48	-1.40	-2.71	-6.17	-6.70	-1.70	-0.23	-0.10	0
13-Jun-99	0	0	-0.48	-1.42	-2.68	-6.24	-6.64	-1.38	-0.23	-0.10	0
16-Jun-99	0	0	-0.50	-1.43	-2.68	-6.31	-6.82	-1.75	-0.18	-0.10	0
9-Jul-99	0	0	-0.48	-1.45	-2.63	-6.44	-6.65	-1.64	-0.23	-0.10	0
12-Jul-99	0	0	-0.48	-1.40	-2.75	-6.30	-6.62	-2.15	-0.23	-0.10	0
14-Jul-99	0	0	-0.48	-1.40	-2.88	-6.32	-6.64	-1.98	-0.23	-0.10	0
23-Jul-99	0	0	-0.46	-1.37	-2.64	-6.40	-6.62	-2.06	-0.23	-0.10	0
15-Aug-99	0	0	-0.48	-1.40	-2.65	-6.33	-6.51	-2.05	-0.23	-0.10	0

Table C2c. Cross section data from Site O in the north gully. Measurements are in feet and taken from left to right, looking downgully.

	0'	2'	4'	6'	8'	10'	12'	14'	16'	18'	20'	22'	24'	26'	28'
18-Apr-99	0	-0.08	-2.25	-4.94	-4.80	-4.64	-4.63	-4.33	-4.26	-3.77	-3.08	-1.70	-0.58	-0.07	0
2-May-99	0	-0.08	-2.31	-4.87	-4.77	-4.67	-4.60	-4.36	-4.24	-3.75	-3.08	-1.61	-0.55	-0.07	0
11-May-99	0	-0.08	-2.31	-4.90	-4.72	-4.65	-4.63	-4.58	-4.32	-4.25	-3.08	-1.62	-0.50	-0.07	0
27-May-99	0	-0.08	-2.65	-4.83	-4.58	-4.65	-4.58	-4.30	-4.20	-3.75	-2.97	-1.60	-0.50	-0.07	0
7-Jun-99	0	-0.08	-2.96	-4.80	-4.58	-4.50	-4.48	-4.32	-4.19	-3.78	-2.93	-1.50	-0.50	-0.07	0
13-Jun-99	0	-0.08	-3.75	-4.78	-4.65	-4.48	-4.55	-4.33	-4.18	-3.82	-2.93	-1.64	-0.51	-0.07	0
16-Jun-99	0	-0.06	-3.20	-4.86	-4.66	-4.48	-4.55	-4.30	-4.18	-3.70	-2.93	-1.65	-0.50	-0.07	0
9-Jul-99	0	-0.05	-3.10	-4.77	-4.72	-4.54	-4.52	-4.25	-4.15	-3.75	-2.93	-1.65	-0.50	-0.10	0
12-Jul-99	0	-0.05	-3.08	-4.75	-4.70	-4.53	-4.52	-4.31	-4.12	-3.68	-2.93	-1.64	-0.50	-0.10	0
14-Jul-99	0	-0.05	-2.86	-4.83	-4.71	-4.53	-4.52	-4.28	-4.18	-3.72	-2.90	-1.64	-0.50	-0.10	0
23-Jul-99	0	-0.05	-3.02	-4.81	-4.72	-4.53	-4.52	-4.27	-4.17	-3.71	-2.93	-1.61	-0.50	-0.10	0
15-Aug-99	0	-0.08	-3.68	-4.80	-4.72	-4.53	-4.55	-4.25	-4.18	-3.68	-2.84	-1.75	-0.45	-0.10	0

Table C2d. Cross section data from Site P in the north gully. Measurements are in feet and taken from left to right, looking downgully.

	0'	2'	4'	6'	8'	10'	12'	14'	16'	18'	20'	22'	24'	26'	28'	30'	32'	34'	36'
18-Apr-99	0	-0.24	-0.54	-2.06	-2.70	-2.63	-2.62	-2.81	-2.67	-2.63	-2.33	-1.88	-1.38	-1.04	-0.83	-0.54	-0.33	-0.18	0
2-May-99	0	-0.23	-0.54	-2.17	-2.67	-2.54	-2.50	-2.52	-2.51	-2.36	-2.18	-1.72	-1.19	-0.88	-0.67	-0.40	-0.25	-0.18	0
11-May-99	0	-0.23	-0.60	-2.08	-2.63	-2.48	-2.50	-2.59	-2.57	-2.40	-2.26	-1.73	-1.21	-0.54	-0.67	-0.40	-0.25	-0.18	0
27-May-99	0	-0.24	-0.53	-2.00	-2.75	-2.62	-2.65	-2.60	-2.38	-2.50	-2.24	-1.85	-1.30	-1.00	-0.50	-0.50	-0.35	-0.25	0
7-Jun-99	0	-0.20	-0.48	-1.90	-2.60	-2.55	-2.55	-2.58	-2.62	-2.40	-2.70	-1.80	-1.25	-0.90	-0.72	-0.41	-0.26	-0.14	0
16-Jun-99	0	-0.22	-0.48	-2.08	-2.57	-2.58	-2.53	-2.75	-2.28	-2.40	-2.28	-1.80	-1.20	-0.90	-0.74	-0.44	-0.26	-0.17	0
9-Jul-99	0	-0.22	-0.61	-1.98	-2.68	-2.61	-2.58	-2.78	-2.54	-2.40	-2.31	-1.84	-1.23	-0.91	-0.73	-0.39	-0.23	-0.13	0
12-Jul-99	0	-0.21	-0.58	-1.94	-2.61	-2.57	-2.53	-2.74	-2.24	-2.38	-2.25	-1.79	-1.26	-0.90	-0.69	-0.39	-0.21	-0.16	0
14-Jul-99	0	-0.21	-0.60	-2.00	-2.63	-2.61	-2.57	-2.67	-2.27	-2.41	-2.29	-1.81	1.25	-0.90	-0.71	-0.38	-0.21	-0.15	0
23-Jul-99	0	-0.22	-0.60	-2.00	-2.63	-2.60	-2.54	-2.67	-2.26	-2.41	-2.30	-1.85	-1.28	-0.90	-0.72	-0.40	-0.23	-0.13	0
15-Aug-99	0	-0.22	-0.60	-2.00	-2.63	-2.60	-2.54	-2.67	-2.26	-2.41	-2.30	-1.85	-1.28	-0.90	-0.72	-0.40	-0.23	-0.13	0

Table C3. Suspended sediment concentration data.

	Sample Bottle Location		
	Bottom	Middle	Top
SSR 1	40104.78	24748.86	36355.59
SSR 2	106598.04	82367.58	58888.96
SSR 3	51198.14	24260.46	
SSR 4	68604.70	42142.47	28267.75
SSR 5	171565.86		
SSR 6	168533.16	74769.47	

Table C4a. Suspended sediment grain size distribution data.

Sample C SSR 1, Top		Sample A SSR 1, Bottom	
Percent Finer Than	Particle Diameter (mm)	Percent Finer Than	Particle Diameter (mm)
93.71	0.08452	79.60	0.07964
93.71	0.05977	79.60	0.05631
93.71	0.04226	75.60	0.04047
90.86	0.03010	73.60	0.02892
88.00	0.02149	67.60	0.02098
79.43	0.01551	61.60	0.01519
59.43	0.01190	51.60	0.01151
45.14	0.00869	39.60	0.00847
33.71	0.00630	31.60	0.00614
28.00	0.00451	27.60	0.00440
25.14	0.00321	21.60	0.00317
22.29	0.00228	17.60	0.00227
16.57	0.00133	13.60	0.00132
13.71	0.00095	11.60	0.00094

Sample N SSR 1, Bottom		Sample Y SSR 2, Bottom	
Percent Finer Than	Particle Diameter (mm)	Percent Finer Than	Particle Diameter (mm)
79.60	0.07964	81.60	0.07898
77.60	0.05687	77.60	0.05687
75.60	0.04047	75.60	0.04047
73.60	0.02892	69.60	0.02938
67.60	0.02098	61.60	0.02149
35.60	0.01663	43.60	0.01617
17.60	0.01283	25.60	0.01252
13.60	0.00918	19.60	0.00902
9.60	0.00656	15.60	0.00644
7.60	0.00467	11.60	0.00461
3.60	0.00333	7.60	0.00330
1.60	0.00237	7.60	0.00233
1.60	0.00137	5.60	0.00135
1.60	0.00097	3.60	0.00096

Table C4b. Suspended sediment grain size distribution data.

Sample D SSR 2, Top		Sample F SSR 2, Bottom	
Percent Finer Than	Particle Diameter (mm)	Percent Finer Than	Particle Diameter (mm)
77.60	0.08042	91.60	0.07514
75.60	0.05723	89.60	0.05378
73.60	0.04090	87.60	0.03837
67.60	0.02966	83.60	0.02769
59.60	0.02164	69.60	0.02078
39.60	0.01640	31.60	0.01683
31.60	0.01229	15.60	0.01289
27.60	0.00881	13.60	0.00918
23.60	0.00630	11.60	0.00652
17.60	0.00454	7.60	0.00467
15.60	0.00322	5.60	0.00332
11.60	0.00231	3.60	0.00236
9.60	0.00134	3.60	0.00136
5.60	0.00096	3.60	0.00096

Sample AF SSR 4, Top		Sample Q SSR 4, Bottom	
Percent Finer Than	Particle Diameter (mm)	Percent Finer Than	Particle Diameter (mm)
91.60	0.07514	91.60	0.07514
91.60	0.05313	87.60	0.05426
89.60	0.03803	83.60	0.03916
83.60	0.02769	73.60	0.02892
67.60	0.02098	43.60	0.02286
29.60	0.01696	21.60	0.01737
23.60	0.01260	19.60	0.01275
19.60	0.00902	17.60	0.00908
17.60	0.00642	15.60	0.00644
11.60	0.00461	13.60	0.00459
9.60	0.00328	11.60	0.00326
7.60	0.00233	9.60	0.00232
5.60	0.00135	7.60	0.00135
5.60	0.00096	7.60	0.00095

Table C5. Water surface height data.

Date of Rainfall Event	CSR	Water Height	Date of Rainfall Event	CSR	Water Height
10 May	A	bad data	11 Jun	A	bad data
10 May	B	bad data	11 Jun	B	bad data
10 May	C	bad data	11 Jun	C	bad data
10 May	D	bad data	11 Jun	D	bad data
10 May	E/F	bad data	11 Jun	E/F	bad data
10 May	G	bad data	11 Jun	G	bad data
10 May	H	bad data	11 Jun	H	bad data
10 May	I	bad data	11 Jun	I	bad data
10 May	J	bad data	11 Jun	J	bad data
10 May	K/L	bad data	11 Jun	K/L	
10 May	M	bad data	11 Jun	M	1.00
10 May	N	bad data	11 Jun	N	1.50
10 May	O	bad data	11 Jun	O	4.00
10 May	P	bad data	11 Jun	P	2.25
26 May	A	bad data	13 Jun	A	5.13
26 May	B	bad data	13 Jun	B	7.25
26 May	C	bad data	13 Jun	C	7.75
26 May	D	bad data	13 Jun	D	12.25
26 May	E/F	bad data	13 Jun	E/F	36.00
26 May	G	bad data	13 Jun	G	0.50
26 May	H	bad data	13 Jun	H	1.25
26 May	I	bad data	13 Jun	I	1.00
26 May	J	bad data	13 Jun	J	5.50
26 May	K/L	bad data	13 Jun	K/L	24.00
26 May	M	0.13	13 Jun	M	0.75
26 May	N	0.11	13 Jun	N	1.00
26 May	O	0.36	13 Jun	O	1.00
26 May	P	0.10	13 Jun	P	2.25
28 May	A	27.50			
28 May	B				
28 May	C	16.00			
28 May	D	21.00			
28 May	E/F	35.50			
28 May	G	12.00			
28 May	H	7.00			
28 May	I	8.50			
28 May	J	14.50			
28 May	K/L	24.00			
28 May	M	1.75			
28 May	N	6.00			
28 May	O	8.50			
28 May	P	12.00			

Table C6a. Survey of Area One for determination of slope of Antelope Mound and monitored gullies. Data reflects survey instrument readings. Instrument height is 61 inches and target height is 128 inches. Inclination and bearing measurements are in degrees, and range measurements are in feet.

1. Survey of transect from top of Antelope Mound down to head of monitored north gully.

Point	Instrument inclination	Bearing	Instrument Range
1	93.6	113.1	949.0
2	93.6	113.0	907.3
3	93.5	112.8	850.0
4	93.6	113.2	786.9
5	93.8	113.8	725.8
6	93.7	113.1	660.5
7	93.7	113.3	599.9
8	93.9	113.1	530.8
9	93.7	113.4	465.0
10	93.9	113.6	399.4
11	93.9	114.3	331.8
12	94.1	115.1	266.4
13	94.3	115.2	199.7
14	95.1	115.3	135.7
15	96.4	116.9	69.2

2. Survey of transect from head to end of monitored north gully.

Point	Instrument inclination	Bearing	Instrument Range
Head	90.0	23.1	5.0
Site M	90.2	327.7	72.8
Site N	88.7	324.1	199.4
Site O	88.8	311.4	315.5
	88.9	308.7	433.4
Site P	89.3	309.4	732.4

Table C6b. Survey of Area One for determination of slope of Antelope Mound and monitored gullies. Data reflects survey instrument readings. Instrument height is 61 inches and target height is 128 inches. Inclination and bearing measurements are in degrees, and range measurements are in feet.

3. Survey of transect from top of Antelope Mound down to head of monitored south gully.

Point	Instrument inclination	Bearing	Instrument Range
1	93.6	61.0	1275.6
2	93.5	61.3	1230.9
3	93.7	62.7	1124.0
4	93.6	62.6	1039.9
5	93.6	62.6	960.5
6	93.5	62.1	925.5
7	93.4	63.1	878.2
8	93.4	63.4	842.7
9	93.5	63.4	756.8
10	93.3	63.8	676.5
11	93.4	63.8	561.6
12	93.6	64.7	482.8
13	93.5	65.3	394.4
14	93.5	65.7	310.5
15	93.9	67.4	216.8
16	95.1	69.7	127.4
17	99.3	70.5	50.3

4. Survey of transect from head to end of monitored south gully.

Point	Instrument inclination	Bearing	Instrument Range
A	97.2	274.5	21.7
B	95.2	285.5	29.6
C	93.9	284.1	38.5
D	93.2	281.2	49.7
SSR 1	92.6	280.6	55.7
SSR 2	91.6	271.9	79.1
RCD 2	92.6	268.6	94.1
G	90.6	265.0	120.3
H	90.5	265.2	130.6
SSR 3	90.3	266.1	141.8
J	90.4	264.7	152.6
SSR 4	90.1	259.8	195.1
RCD 3	90.7	258.5	207.8

Table C7. First survey of sediment catchment. Data reflects survey instrument readings. Instrument height is 61 inches and target height is 74 inches. Inclination and bearing measurements are in degrees, and range measurements are in feet.

Point	Instrument inclination	Bearing	Instrument Range	Point	Instrument inclination	Bearing	Instrument Range
1	94.5	169.4	16.0	29	90.7	296.3	365.3
2	92.5	171.9	34.8	30	90.9	299.0	381.4
3	91.6	167.4	59.3	31	90.8	304.0	431.0
4	91.6	168.5	80.8	32	90.7	307.6	401.2
5	91.3	168.8	96.4	33	90.8	311.6	424.3
6	91.4	172.4	120.4	34	90.7	313.7	464.4
7	91.2	178.7	142.5	35	90.7	316.0	524.1
8	91.2	179.6	156.6	36	90.9	317.8	560.8
9	91.3	181.6	173.7	37	90.7	322.5	537.9
10	91.2	184.8	184.9	38	90.8	326.2	510.5
11	91.3	190.2	177.6	39	90.7	330.1	488.6
12	91.3	194.7	160.9	40	90.7	332.4	474.9
13	91.2	198.9	170.9	41	90.7	337.9	454.3
14	91.1	205.8	179.0	42	90.7	344.8	433.2
15	91.1	217.6	176.3	43	90.6	344.3	343.1
16	91.2	222.3	182.9	44	90.7	344.5	342.7
17	91.0	236.4	177.4	45	90.8	345.7	318.5
18	91.1	247.0	197.1	46	90.6	346.1	293.8
19	91.1	251.3	216.9	47	90.6	345.3	232.7
20	91.0	254.3	226.0	48	90.6	345.2	185.2
21	90.8	260.9	218.4	49	90.6	346.3	142.8
22	90.9	266.0	237.0	50	90.6	347.1	107.2
23	90.7	270.7	250.7	51	90.9	346.9	78.8
24	90.8	272.7	270.7	52	90.9	349.7	64.7
25	90.9	273.4	306.9	53	90.6	340.4	59.4
26	90.8	279.4	319.2	54	90.2	321.9	24.2
27	90.8	283.7	328.9	55	104.0	329.8	2.5
28	90.8	288.9	347.7	56	87.4	284.1	25.6

Table C8a. Second survey of sediment catchment, done for sediment thickness evaluation. Data reflects survey instrument readings. Instrument height is 61 inches and target height is 34 inches. Inclination and bearing measurements are in degrees, and range measurements are in feet.

1. Survey of sediment thickness locations in catchment.

Point	Instrument inclination	Bearing	Instrument Range	Sediment Thickness (in)	Notes
1				14.0	Submerged zone
2	90.1	329.2	663.0	15.0	Submerged zone
3	90.3	329.6	657.6	11.0	Submerged zone
4	89.8	334.4	630.8	21.0	Submerged zone
5	90.8	342.7	583.4	21.0	Submerged zone
6	91.8	342.6	506.0	4.0	Submerged zone
7	90.0	334.8	529.3	22.0	Submerged zone
8	90.1	332.9	540.7	25.0	Submerged zone
9	91.1	328.2	550.9	19.0	Submerged zone
10	90.3	326.3	552.6	4.0	Submerged zone
11	90.1	319.3	488.1	10.0	Submerged zone
12	90.1	322.1	464.5	13.0	Submerged zone
13	89.8	328.9	424.0	18.0	Submerged zone
14	90.2	336.0	396.1	30.0	Submerged zone
15	90.2	347.9	376.3	15.0	Submerged zone
16	89.8	348.8	319.4	11.0	Submerged zone
17	90.0	337.8	311.9	26.0	Submerged zone
18	90.0	322.7	343.5	25.0	Submerged zone
19	90.0	315.1	369.9	10.0	Submerged zone
20	90.1	311.1	385.6	12.0	Submerged zone
21	89.7	311.6	310.1	12.0	Submerged zone
22	89.4	318.1	272.7	16.0	Submerged zone
23	89.2	325.7	247.7	15.0	Submerged zone
24	89.2	336.2	231.0	33.0	Submerged zone
25	89.2	348.5	224.9	12.0	Submerged zone
26	89.0	339.7	196.2	46.0	Submerged zone
27	89.0	331.6	201.2	23.0	Submerged zone
28	89.3	321.4	217.9	10.0	Submerged zone
29	89.8	315.2	232.6	9.0	Submerged zone

Table C8b. Second survey of catchment pond, for size refinement and sediment thickness determination. Data reflects survey instrument readings. Instrument height is 61 inches and target height is 34 inches. Inclination and bearing measurements are in degrees, and range measurements are in feet.

2. Survey of sediment thickness locations in catchment (continued).

Point	Instrument inclination	Bearing	Instrument Range	Sediment Thickness (in)	Notes
29	0.0	313.6	163.0	36.0	Intermediate zone
30	0.0	329.9	141.9	32.0	Intermediate zone
31	0.0	347.6	127.1	48.0	Intermediate zone
32	0.0	309.5	134.4	22.0	Intermediate zone
33	0.0	314.7	99.4	29.0	Intermediate zone
34	0.0	343.7	84.9	44.0	Intermediate zone
35	0.0	318.4	72.0	24.0	Intermediate zone
36	0.0	324.7	46.4	24.0	Intermediate zone
37	0.0	358.8	36.7	34.0	Intermediate zone
1	91.0	143.5	116.9	12.0	Aerated zone
2	91.4	125.7	163.7	12.0	Aerated zone
3	91.4	115.7	147.1	12.0	Aerated zone
4	91.5	94.8	118.0	12.0	Aerated zone
5	90.8	60.2	76.7	12.0	Aerated zone

3. Survey measurement to location of survey instrument from previous survey.

Instrument inclination	Bearing	Instrument Range	Sediment Thickness (in)	Notes
90.3	356.6	199.8	N/A	

Table C9. Cone penetrometer data.

Distance From Origin (ft)	Penetrometer Reading	Distance From Origin (ft)	Penetrometer Reading
0	3.02	26	0.01
1	3.95	27	0.92
2	4.45	28	4.45
3	4.95	29	5.87
4	3.70	30	1.25
5	3.94	31	5.50
6	4.06	32	3.50
7	4.76	33	5.40
8	2.40	34	5.48
9	3.69	35	5.50
10	5.40	36	1.59
11	4.08	37	2.68
12	2.15	38	1.20
13	3.50	39	5.50
14	5.32	40	5.50
15	4.80	41	5.50
16	0.31	42	5.50
17	2.55	43	5.50
18	0.54	44	5.50
19	2.29	45	5.50
20	4.47	46	0.51
21	5.50	47	0.58
22	5.50	48	5.50
23	2.59	49	5.50
24	4.11	50	4.60
25	0.04		

APPENDIX D

SWAT Model Input Data and Methods

The input for the SWAT run is described in the same order as the model's sequence of prompts appears onscreen. A ten-meter resolution DEM of Fort Hood provided by the Fort Hood ITAM (Installation Training Area Management) GIS section was used. The DEM was not masked, and the stream network was burned in. Four outlet points were chosen, and three watershed outlet points were selected. This was done to confine the areas analyzed during the run to the study site. No reservoirs or point sources were added.

A Fort Hood-supplied ArcView shape file was used for land use designation. The file was converted to a grid in ArcView and imported into SWAT. The land use of the study area is "maneuver area". Since "maneuver area" is not an input option in SWAT, the "southern rangeland" land use option was selected as the input parameter, indicating vegetation throughout the study area.

Digitized Soil Survey Geographic Database (SSURGO) data from Coryell County was used as the soil input. The file was converted to a polygon file in ARC/INFO, imported to ArcView, converted to a grid file, and imported into SWAT. The specific S5ID designations of the soils were then manually entered to complete the input.

The Multiple Hydrologic Response Units option and default values were used. Rainfall and temperature data from the National Climate Data Center and Robert Gray Army Airfield on Fort Hood from 1993 through 1998 accessed at the National Climate

Data Center website (Lot, 1999) was used to create an input file. Where daily rainfall or temperature data were missing; a value of –99 was entered, which caused the program to ignore the input value and use an internal simulator to calculate a value for that day. The U.S. database weather simulation option was selected, since the site was near to and in a similar setting as existing sites. The system default values for groundwater data were selected.

During the input files creation step, the watershed configuration file, soil data, weather generator data, general HRU data, main channel data, groundwater data, water use data, soil chemical data, and pond data were generated. The management data sub-option for plant heat units calculated from local climatic conditions was chosen. The model was run for a five-year period (1994-1998) using daily rainfall and temperature data from Robert Gray Army Airfield on Fort Hood (shown in Fig. 1) and the other input data.

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